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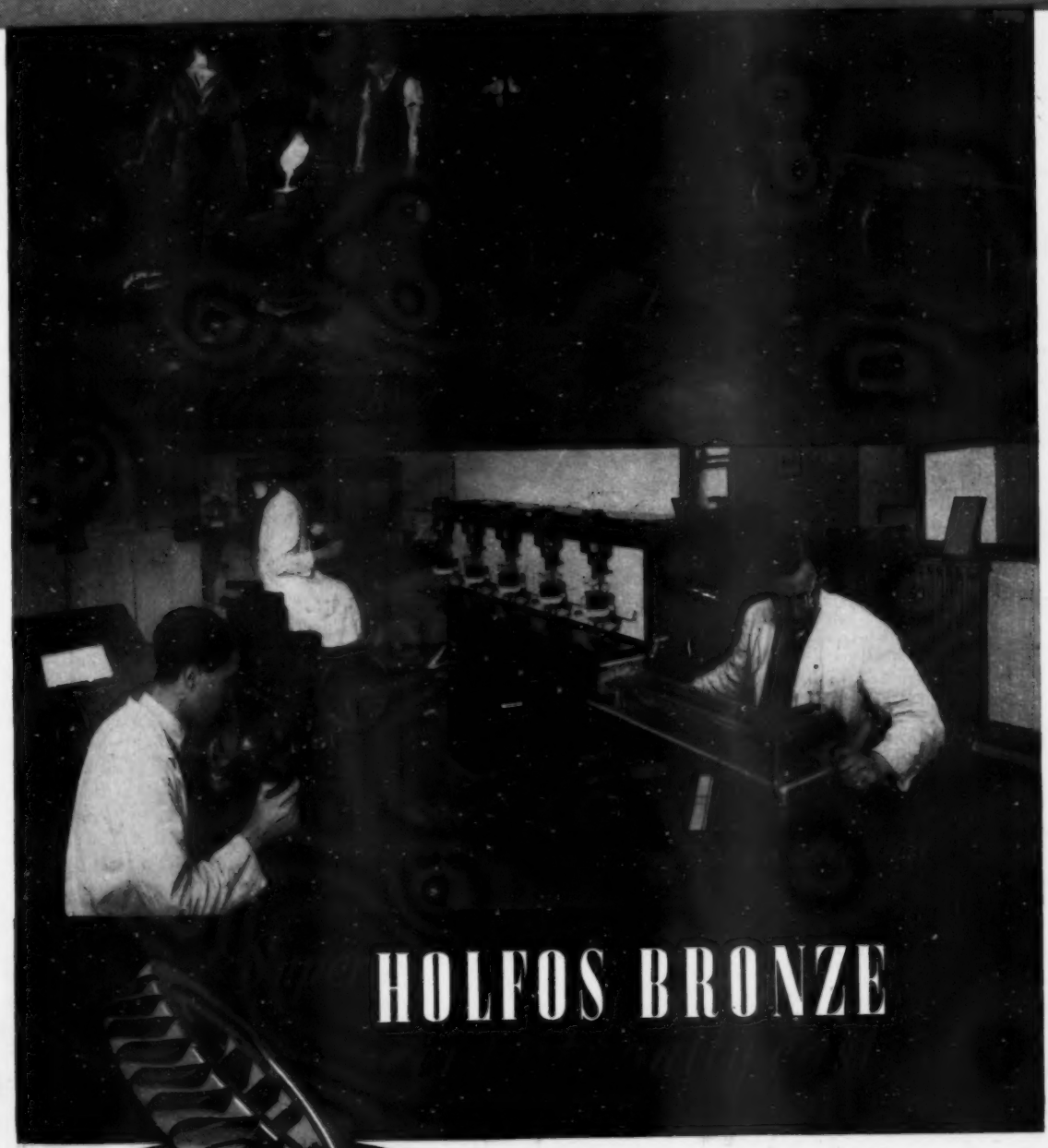

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The British Journal of Metals

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THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

MAY, 1944 VOL. XXX. No. 175

British Heat-Treatment Furnaces

THOSE familiar with conditions in the furnace industry at the end of the last great war will appreciate that manufacturers had rather a thin time, especially those firms which specialised in heat-treatment furnaces. During the period of that war, as during the present conflict, manufacturers were called upon to meet abnormal demands for heat-treatment furnaces designed in many respects to deal with unfamiliar components in great variety and on a mass production basis. They were essential to expedite production for the armament programmes then scheduled. At the end of that war many orders for heat-treatment furnaces, some nearing completion, were cancelled, while hundreds of furnaces which had been used solely for armament work were thrown on the market and sold by merchants at ridiculous prices. This unsatisfactory method of dealing with surplus furnaces reacted on furnace designers and manufacturers, and it is not surprising that some of them had a particularly thin time for some years after the war.

The industry is again experiencing abnormal conditions of prosperity from a similar cause, and, naturally, all manufacturers are giving an occasional thought to the future and doubtless expressing the hope that steps taken at the conclusion of the present hostilities will prevent a repetition of the conditions previously experienced.

In spite of the difficulties whice arose after the last war, tremendous strides were made in the design and construction of all types of furnaces between the two wars. Compared with even the best of the heat-treatment furnaces operating during the last war, modern furnaces can be regarded as high-precision machine tools. In addition to controlled atmospheres within the furnace chamber, and of forced circulation for more uniform heating, further developments in heat-treatment equipment include the use of robust tubular elements—operating from a low voltage for fan circulation furnaces for tempering and other low-temperature processes. The uniformity of temperature, within very close limits, is an outstanding feature of both electric and gas-fired furnaces; this is not only an indication of the care given to insulation in the designing of plants, but also of the accuracy of control instruments for regulating the heating. In the gas furnace field the recuperative radiant tube furnace has found an increasing application, especially for the continuous clean hardening of a wide variety of small parts. This type of furnace excludes the products of combustion from the furnace chamber, which can be supplied with any prepared protective atmosphere. A more recent development, which offers distinct possibilities in the more efficient use of fuel or electricity, is the use of permeable refractories as linings of furnaces.

Reference has only been made to the major advances, but it can be said that the design and manufacture of British heat-treatment furnaces is of a very high standard, and it is extremely doubtful whether they are surpassed by any constructed abroad. It will be appreciated, however, that the demands on the industry to meet war-time requirements has greatly increased the output capacity of firms engaged in this work. Most manufacturers have extended their works and new manufacturers have appeared. It is probable, therefore, that home requirements after the war will be upset considerably by present conditions, just as home requirements after the last war were conditioned by the efforts made by the industry during that war, but it must be remembered that the demand has been much greater during the past four years. With its present capacity there seems no doubt that the contribution of the British furnace industry to the export trade should be substantial, although, after a lapse in normal overseas contacts with former profitable markets, much careful work will be necessary to build up connections in these markets, either in restoring or making new contacts.

It is difficult even to speculate on what will take place in the furnace industry after the war, there seems little doubt, however, that on the ferrous metal side the heat-treatment furnaces which have been supplied during the past four years to various motor manufacturers for carburising, hardening and tempering of aero-engine parts are of very modern design and are likely to be in excess of requirements in the post-war motor-car and civil aviation industries. It is probable that this is also the position in regard to furnace plant supplied to manufacturers of drop forgings.

In the non-ferrous industries dealing with copper and copper-alloys considerable development may be reasonably anticipated, which will call for additional plant, particularly the atmosphere-controlled type of muffle furnace for bright annealing the product through all its processes of manufacture to the finished article. For aluminium alloys and magnesium alloys a very large number of modern furnaces are in operation, probably a larger number than normal conditions will need, unless new alloys requiring higher temperature treatment are developed. Such developments are possible, in which case the existing furnaces would probably be unsuitable, or would need reconstruction to satisfy the new conditions. The discovery of new alloys and processes would cause the light metal industry to develop

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

rapidly in peace-time activities and would offer great opportunities for post-war furnace construction.

The immediate post-war prospects of the furnace industry, so far as this country is concerned, is bound to be affected by Government regulations as to fuel allocation and usage, but, on the whole, reasonable optimism prevails in the industry that any slackening in demand will be of a temporary character. It is probable, for instance, that there will be considerable export demand for furnaces to the liberated countries of Europe during the early post-war years, though a good deal of this work would be carried out with local labour and material. But preparations should be made for marketing proved standard types of furnaces at short notice as demands may arise before hostilities cease.

The Future of the British Aluminium Industry

THE editorial published in our March issue under the above heading has caused many comments, some of which were published as correspondence in our last issue. Since that issue was published, we have received extensive comments from Mr. W. C. Devereux, which were considered to be unsuitable for presentation in the form of correspondence; his views are given elsewhere in this issue in the form of an article, but since they are related to the original editorial, our contributor briefly comments upon the views expressed by Mr. Devereux in this issue and by Mr. Cunliffe in the correspondence published in the last issue.

Some sensitiveness seems to have been shown at the mention of price regulation, and it is necessary to point out that in the original editorial on the subject our contributor was in no way concerned with the efficiency or morality of cartels or price agreements. His general criticism of the aluminium industry is that the prices of primary metal and a number of wrought aluminium alloy products at present do not bear a reasonable relationship to the cost of their production. He fears that the manufacturers concerned are jeopardising the post-war prospects of their industry by preferring to refund a large proportion of their profits to the Supply Ministry instead of adjusting their prices to bring them into closer relationship with current cost. One of two motives must be responsible for the pursuance of such a policy. Either the industry believes that its market after the war is assured at present prices, or it is reconciled to finding no larger market for its products than was the case before rearmament commenced.

That the aluminium industry has made steady progress since its inception in this country few can doubt, but, in comparison with many countries, the expansionist policy followed in the production of aluminium has been slow and deliberate. By 1938, for instance, this policy had brought us to ninth place in the list of the world's producers, whereas in the list of consumers we ranked as third. This is not intended as a criticism of the policy then adopted, because there are many sound reasons for the production of aluminium in this country lagging behind that of many other countries—notably the scarcity of high bauxite and the comparatively poor water-power facilities.

But difficulties encountered in the production of aluminium in this country should not be allowed to check the bright prospects the post-war period offers for the rapid advancement of the industry. It is now well known that the application of aluminium alloys, even in the limited field of aircraft engine and frame construction, has been invaluable to the war effort; alloys have been submitted to the severest tests in service and have successfully responded to the stresses their components have been designed to bear. Apart from the now familiar characteristics and properties of these alloys, the ease by which they can be fabricated and machined is more generally known.

The normal progress of the aluminium industry was interrupted by rearmament at an early and critical stage in its development; it is surely not too much to expect that it is in a position to make a flying start after the war, and, at least, commence with the advancement it would have made under normal peace conditions. But if the use of aluminium and its alloys is to advance at the rate warranted by the qualities of the metal and production costs, it would seem that a progressive marketing policy is required now.

Non-Ferrous Metal Smelting

THE smelting of certain non-ferrous metal ores was carried out in this country for many centuries. Britain, however, is not very well endowed with mineral resources and the reasons for her decadence in non-ferrous smelting are well known. Until the end of last century her position in this respect was not nearly so unsatisfactory as to-day. Swansea and other centres formerly received complex ores from all over the world, apart from domestic ore. To-day there are practically no domestic ores and complex ores have ceased to come.

From time to time practically all countries of the world take stock of their position, with regard to basic metals and minerals, and even the United States, which is probably better endowed by nature than most countries, recognised many years ago through the Leuth Committee that it must import a considerable range of essential minerals. One of its conclusions is of particular interest—viz., "Minerals should be concentrated, smelted or fabricated near the source of supply with limitations." As a general resolution this is quite unexceptional, but as the two last words indicate, it is not of universal application. The zinc industry of Belgium before the war, which was so closely interlocked with many other industries in that country, shows this very clearly, and an exact parallel is to be found in the oil-refining industry of this country.

Europe as a whole, apart from Russia, is not well endowed with mineral resources, and although some countries are better off than others—Spain, for instance—no single one, and indeed no contiguous group, is self-sufficing. And yet within the British Empire itself there are sufficient metals and minerals, not only for its own requirements, but, in most cases, to provide a surplus for export. True, that surplus may reach other countries in the form of concentrates, but Great Britain is far too dependent on other countries for its essential requirements, and it should do more of the necessary refining and fabricating of minerals than it does to-day.

In this connection it is noteworthy, as announced elsewhere in this issue, that an association has been formed with the object of looking after the common interests of British smelters of primary non-ferrous ores. There is undoubtedly a need for such an association, but there is a more pressing need for a national consideration of the whole subject.

The Rapid Photometric Determination of Beryllium in Beryllium-Containing Minerals and Rocks

By G. H. Osborn and W. Stross*

Although it is generally recognised that Beryl is not a rare mineral, it is only rarely that beryllium is shown in the analyses of igneous rocks ; this fact is largely due to the analytical problem involved. Yet the growing importance of beryllium as metal necessitates its accurate and speedy determination in Beryl and other minerals and methods so far applied have, many disadvantages; in the present method, however, developed by the authors, accurate and reproducible analyses are rapidly obtained. The method is fully described.

THE increasing importance of beryllium as metal in industry has necessitated the accurate and speedy determination of beryllium in Beryl and other minerals, but the methods[1], [2] so far described are either tedious and require great manipulative skill, or are not capable of any real accuracy, owing to the great similarity in the chemistry of aluminium and beryllium. A. W. Groves[3] has clearly pointed out that beryllium has very rarely been returned in the analysis of igneous rocks, although as Clark and Washington[4] remark, the fact that Beryl is not a rare mineral† indicates that beryllium is fairly widespread. Groves goes on to point out that with regard to beryllia it is probably true to say that the number of rock analyses, in which this constituent has been determined may be counted on one's fingers, the analytical problem being mainly responsible for this state of affairs.

Among the chemical methods known so far for the determination in minerals, it seems that the method proposed by H. Fischer[1] is the most specific, but it is difficult and tedious. The present knowledge of the occurrence of beryllium in rocks is almost entirely based on the classic paper by V. M. Goldschmidt and Cl. Peters[5] using physical methods. The method proposed by Sandell,[6] based on the experiments of H. J. L. Zermatten[12] using the specific fluorescence of beryllium with morin in alkaline solution for the determination of beryllium in rocks, is probably the best attempt at chemical determination yet reported, but this method also is difficult and tedious, and seems to be semi-quantitative only ; might, however, offer more strictly quantitative possibilities if a modern fluorimeter were used. There is also the danger that the small samples (0·1 gram) recommended by this author, owing to the great sensitivity of the reaction, might not be representative of the often extremely inhomogeneous material under investigation.

The method now proposed was developed for the determination of beryllium in aluminium alloys, and this application will be described elsewhere[7] in detail. The method is based on the qualitative test developed by Komarowsky and Poluektoff,[8] using the dye *p*-nitrobenzene-azo-orcinol.‡ This reagent gives a bright yellow colour in neutral and moderately alkaline reaction, but turns to reddish-brown in the presence of beryllium and alkali. The intensity of this colour is an almost linear function of the beryllium concentration over a certain range provided the optimum conditions as given below are strictly observed.

The colour change, although perfectly definite to visual observation as a qualitative test is, however, difficult to estimate quantitatively without the use of adequate photometric instruments as described below in detail.

The decisive factor for full development of the reaction is the maintenance of correct alkalinity, the range of which is rather narrow and critical. If the alkalinity is not sufficiently high, little or no colour change is produced, and if too high the dye develops a brownish hue even in the absence of beryllium. Accurate and reproducible results can, however, easily be obtained if a buffered solution is used in controlled amounts.

The dye *p*-nitrobenzene-azo-orcinol is a reddish powder, sparingly soluble in organic solvents and in caustic. We used a solution of 0·025 grams digested with 100 ml. N/10 NaOH and filtered through a No. 42 Whatman filter to remove any insoluble impurities. This solution, kept in brown bottles, is stable for several weeks at the least. The other solutions required are simply 5N and 2N NaOH, 0·64 molar boric acid, and a standard solution of a beryllium salt (e.g., $BeSO_4$), and for calibrating purposes for rock analysis, a solution of high purity aluminium in caustic soda. With these solutions a calibration graph can be obtained by mixing varying amounts of beryllium up to about 0·08 mg. with 5 ml. boric acid solution, 2·7 ml. of the 2N NaOH (this being the optimum of alkali addition) followed by water to 19 ml. plus 6 ml. of the dye solution. The colour (which develops instantaneously and shows little tendency to fade) is then measured with an appropriate instrument. We used both the Zeiss "Pulfrich" photometer and

* A letter delivered before the Mineralogical Society, Burlington House, London, March 23rd, 1944.

† According to C. H. Mathewson (*Metal Industry*, **64**, 1944, p. 150) the frequency of Be in the crust of the earth is equal to that of boron, ten times that of mercury and a hundred times that of bismuth.

1 (*a*) H. Fischer "Beryllium and its Alloys" Scientific Publications of the Siemens Company, 1932. The Chemical Catalog Co., Inc., New York; (*b*) Wissensch. *Veröff.a.d. Siemens-konzern*, vol 5, part 2 (1926), p 99; (*c*) *Zsch. anal. Chem.*, **73** (1928), 54.

2 Treadwel and Hall, *Analytical Chemistry*, vol 2, 9th ed.

3 A. W. Groves, "Silicate Analysis" T. Murby and Co., London, 1937.

4 Clark and Washington. Prof. Paper 127, U.S. Geological Survey, 1924-32.

5 V. M. Goldschmidt and Cl. Peters, *Nachr. Gesell. Wiss. Goettingen Math. Physik. Kl*, 1932, 360–376.

6 E. B. Sandell, *Ind. Eng. Chem. Anal.* ed., vol. 12, 1940, p. 674.

‡ Obtainable from Messrs. Hopkin and Williams, St. Cross Street, London.

7 W. Stross and G. H. Osborn. (In press.)

8 A. S. Komarowsky and N. S. Poluektoff. *Mikrochem.*, **14**, 315 (1933).

the "Spekker" absorptiometer (A. Hilger)‡; for the "Pulfrich" we recommend for minerals the use of a 1 cm. cell and S50 filters, and for the "Spekker" a 2 cm. cell and Calorex heat-absorbing plus Ilford 604 Spectral filters, the filament lamp being used in preference to the mercury lamp. The light absorption of the blank (i.e., dye plus caustic and boric acid, but Be free) is considerable and must therefore be allowed for. This is done on the "Pulfrich" by filling the compensation cell with the "blank"; on the "Spekker" by deducting the blank extinction reading. For the Spekker the use of an asymmetrical filter for the purpose of compensating for the blank is recommended,[7] and extends the useful range of the instrument. The calibration graph will vary somewhat with the particular batch of dye and of filters. Typical values as obtained in our laboratories are given in the following table:—

Mg Beryllium in 25 Ml	Extinction Pulfrich	Extinction Spekker
0·02 ..	0·245 ..	0·35
0·04 ..	0·415 ..	0·615
0·06 ..	0·515 ..	0·795
0·08 ..	0·595 ..	0·93

As already pointed out, the graph is not strictly linear, indicating that the amount of dye used is nearly exhausted by the higher beryllium concentrations. Higher dye concentrations in relation to the amount of beryllium are not recommended as the higher blank value restricts the useful range of the instruments to an inconvenient degree. If higher concentrations of beryllium are present suitable aliquots should be taken, this involving a certain dilution error for higher ranges.

It will be clearly seen that we are keeping as near as possible in the range where the slope of the calibration graph is considerable and the graph nearly linear, and therefore the accuracy is optimal. H. Fischer[1] also bases his method on the colour change, promoted by beryllium, of a dye quinalizarin; he, however, uses a kind of colorimetric titration in which the end point represents the total exhaustion of the reagent. This necessarily brings him (apart from the great tediousness of his procedure) definitely into the flat part of the graph, that is, into its most insensitive and thus most unfavourable region.

p-Nitrobenzene-azo-orcinol, while not entirely specific for beryllium, is only influenced by a few other elements, most of which are very sparingly soluble in caustic. The presence of alumina and silica is without influence for practical purposes, and since these two form the major constituents of beryllium minerals this simplifies the determination to an extraordinary degree. Zinc gives a reaction similar to beryllium, but its sensitivity is many times smaller; copper interferes even in the small amounts soluble in caustic, but both these elements can be easily removed (e.g., by electrolysis or as the sulphides, the beryllium reaction being very insensitive to H_2S excess).¶ For further information about the interference of other elements and how to avoid them, see[7].

The main problem which confronted us in the application of the reaction to minerals was to obtain by simple means a solution of the total beryllium in caustic. This problem appeared from the literature to be a far from simple one. H. Fischer emphasises the necessity when dealing with beryl of at least a double protracted fusion, first with sodium carbonate, and then another fusion with potassium bisulphate. Using his directions, we ourselves failed to obtain reproducible results, and as we continually obtained low results we investigated the reaction. We found that if the fusion with sodium carbonate was not long enough incomplete attack resulted; if, however, the fusion was intensified and protracted the sodium beryllate broke down into an insoluble compound, presumably the α-hydroxide first observed by Vauquelin,[9] thus causing errors which were frequently very considerable. This method of attack is therefore, to say the least, difficult, and certainly open to error. Another process frequently recommended is that suggested by Copaux[10] of fusion with sodium silicofluoride; this process is open to serious objections also—e.g., the length of time required, the destructive action on the crucibles, and the difficulty of removing the fusion product from the crucible walls.

Other workers (6) use a double fusion with caustic soda followed by extraction with ice. This process is tedious and open to the objection that some Be may remain insoluble after the alkali attack. In our case, even if the attack were successful, adjustment of the alkalinity for the final reaction would be very difficult.

We therefore experimented along other lines and found that powdered anhydrous borax gave an ideal fusion resulting in a perfectly clear melt in a very short space of time. In the case of Beryl, Chrysoberyl, Phenacite and Euclase, this melt was entirely soluble in caustic (except for traces of Fe present) while in the case of more complex minerals, such as Gadinolite, Helvite and Meliphanite a caustic insoluble fraction was found. In such cases, however, the berylliom passed into solution as sodium beryllate, where it could be estimated very simply. Based on these experiments, the following procedure for the estimation of beryllium in minerals was adopted and found successful.

Procedure for Minerals

20 mgs.‖ of the finely powdered material are weighed into a platinum crucible and thoroughly mixed with 200 mgs. of powdered borax. The crucible is placed into a muffle furnace at 900° to 1,000° C. until completely fused. This usually takes about 10 mins. or less. The melt is then extracted by heating with 40 mls. of 5N caustic soda and when extraction is complete the solution is made up to 100 mls., mixed and filtered (even if apparently clear) through a 542 Whatman filter to remove any slight turbidity. The solution is now 2N as to NaOH and 2·7 mls. are therefore pipetted into a 25 ml. measuring cylinder for the photometric measurement, or, if a smaller aliquot is taken (e.g., for Phenacite) the requisite amount of 2N NaOH is added. 5 ml. of the boric acid are now added, the volume is made up to 19 ml. with water, followed by 6 ml. of the dye solution. After mixing, the extinction is measured under the conditions as outlined above, and the amount of beryllium present read off from the calibration graph. The time taken for a single determination need not exceed about half an hour, and several determinations can be made in parallel without much increase in time taken.

This technique covers the range of beryllium contents from 2% upwards. If minerals are being examined which

‡ General working instructions for the Pulfrich can be found—e.g., in "The absolute Colorimetric Analysis of Metals by the Use of the Pulfrich Photometer," Carl Zeiss (London), Ltd., obtainable from Messrs. Foyles; for the Spekker absorptiometer in E. J. Vaughan, "The Use of the Spekker Photo-electric Absorptiometer in Metallurgical Analysis," Institute of Chemistry, 1941.

¶ Copper is of extremely rare occurrence in beryllium-containing minerals and its removal will therefore hardly ever be necessary in mineral analysis.

‖ It will be seen that only a small part of this material is used in the final stage, so that, whenever desirable, very much smaller samples—e.g., 2 mgs. and even less, could be taken; the method is therefore truly a micro-method.

9 Vauquelin. *Annales de Chimie*, **26**, 155 (1798).

10 Copaux. *Compt. rend.* (1919), **168**, 610.

are likely to contain less than this amount, either a larger sample—e.g., a 100 mgs.—should be taken (with a corresponding increase of borax, but not of NaOH) or the 20 mg. sample recommended by us should be extracted in less alkali—e.g., 10 mls.—so as to allow the taking of a larger aliquot without exceeding the permissible alkalinity.

The minerals examined by us using the above technique and the results obtained are given in Table I below :—

TABLE I.

Mineral	Origin.	Theoretical Be-content	Be-content Found
Beryl $3BeO.Al_2O_3.6SiO_2$	Ural Mts.	5	4·8
Chrysoberyl $BeO.Al_2O_3$	Ekaterineburg, U.S.S.R.	7	6·5 (See text)
Gadinolite $Be_2FeY_4Si_2O_{10}$	Ytterby, Sweden.	3·7	3·35 3·30
Euclase $2BeO.Al_2O_3.2SiO_2.H_2O$	Minas Geraes Brazil	6·2	6·2 6·2
Leucophanite $BeF.NaO.2SiO_2.CaO$	Brevig, Norway.	3·7	3·5 3·55
Phenacite $2BeO.SiO_2$	Ural Mts.	16·2	17·5 17·5
Helvite $3(Mn.Fe)BeSiO_4$	Langesund, Norway	1·5	(See text) 0·3 0·29
Meliphanite $BeO.BeF.NaO.3SiO_2.2CaO$	Fredriksvarn, Norway	4·6	2·95 3·05

Some of the specimens examined could be seen visually very clearly to be very impure—e.g., the Helvite, which mineral, although stated by Spencer[11] normally to contain no zinc, was found polarographically, in point of fact, to contain 1·5% of zinc. In these cases of impure minerals we were, however, able to obtain reproducible results and where we had pure specimens of mineral—e.g., Euclase—we obtained results agreeing with the theoretical. In the case of Chrysoberyl, our sample was found to contain 5·4% of FeO, thus giving only 94·6% of Chrysoberyl, on which the theoretical beryllium content is 6·62% of the total sample. It will be seen that the results obtained by us were in very good agreement with the theoretical. It may also be mentioned that published analysis of beryls[13] show even greater deviations from the theoretical amounts than those found by us on our specimen. In the specimen of Beryl examined by us, the silica content was 4% higher than the theoretical which doubtless accounts for a lower Be content.

The Determination of Beryllium in Rocks

The procedure adopted for minerals involving a simple fusion with borax could not, unfortunately, be applied to rocks, owing to the fact that the large samples of rock (required in consequence of the extremely small beryllium content) would necessitate unmanageable amounts of borax to take into solution. Attempts were made to volatilise the silica by treatment with HF and sulphuric acid, followed by fusion of the residue with borax. This led to a failure owing to the fact that some of the material remained insoluble and infusible with the borax glass. Attempts were also made to fuse the rock with carbonate fusion mixture, but as had been observed by Fischer *et al.* some of the rock remained unattacked and further fusion treatments with fusion mixture and potassium bisulphate were required. After many failures, the following procedure was worked out and seemed to give positive and reproducible results on some granite pegmatites from the Mourne Mountains (average Be content 0·00077%), and also satisfactory recovery of small amounts of Euclase* added to these granites. Owing to the difficulty at the present time of obtaining specimens, we have not been able to extend the investigation to other rocks, and therefore cannot say whether the method is universally applicable for rocks, but we see no theoretical reason why it should not be so. The amount of material to be taken for analysis will naturally vary with the expected beryllium content. We normally had 1·5 grams represented in the final stage of the determination, but it should be possible to use 3 grams. As our method is capable of finding and measuring from 5 micrograms of beryllium upwards this would enable a content of about 0·00015% beryllium to be determined with ease.†

Procedure

The finely powdered material is weighed into a platinum crucible, and to it is added sulphuric acid (approximately 1·5 ml. per gram of rock); hydrofluoric acid is then added dropwise (if possible from a pipette made from plastic material—e.g., Distyrene Polystyrene). The reaction is violent, but is soon over. The crucible is then filled with hydrofluoric acid and evaporated on a hotplate until no further fumes of SO_3 are evolved. The crucible is then strongly ignited to convert the sulphates present to the oxides. These are then fused carefully with potassium bisulphate to a clear solution. The melt is allowed to cool, and then dissolved in excess of hydrochloric acid. If at this stage any residue whatsoever is observed it should be filtered off carefully, washed, dried, ignited and re-fused with powdered borax. This melt is then extracted in the same HCl solution on a hotplate until everything is in solution. The hydroxides of iron, aluminium and beryllium present are now precipitated by adding a slight excess of ammonia and boiling for a few moments. These hydroxides are filtered off, washed well, and the precipitate digested with a calculated excess of NaOH. The calculation is based on the following principle: Sufficient NaOH must be added to form the aluminate from the calculated aluminium content of the sample (0·74 ml. 5N NaOH per 100 mgs. of aluminium) plus an excess equivalent to 5·4 ml. 2N for the aliquot to be represented in the photometric measurement. This latter figure is based on the fact that the final volume for the photometric measurement is to be 50 mls. in the case of rocks; the final concentration of free alkali is thus the same as explained above for the minerals. The liquid is filtered through a Whatman 541 filter into a measuring cylinder and washed well, the volume of filtrate and washings being governed by the consideration of the final aliquot to be taken. If, after adjusting the volume and mixing, a slight turbidity develops, the solution is refiltered through a dry finer filter. The correctness of the alkalinity adjustment can, for safety, be checked by titrating a small aliquot using phenolphthalein as indicator. A suitable aliquot (representing—e.g., 1·5 grams of granite and 5·4 ml. 2N NaOH in excess of the caustic required to form the aluminate) is pipetted into a 50 ml. measuring vessel, 10 ml. of boric

11 L. J. Spencer. "Thorpe's Dictionary of Applied Chemistry," vol 3, page 547.

12 H. J. L. Zermatten. *Kon. Aka. Wetenschappen te Amsterdam*, vol. 36 (1933), p. 898.

13 J. Jacob. "Drei Analysen von Beryll." *Schweiz. Min. Petr. Mitt.*, 1938, vol. 18, p. 607–609.

* The amounts of Euclase taken with a 5 gram sample of granite were between 1 and 2 mgs (equivalent to 0·0012 to 0·0024% of Be of the sample taken), the accuracy of this weighing, and therefore also the knowledge of the accuracy of the recovery, being limited by the fact that we did not have at our disposal any balance more sensitive than 0·2 mgs.

† In the discussion on this paper Prof. V. M. Goldschmidt was kind enough to point out that this method might be useful for the determination of Be in Coal Ash, where he had recently found this element to be present in appreciable quantities.

acid, and 12 ml. of the dye are added and the volume made up to mark. The optical measurement is then performed on the "Spekker" as above, using, however, a 4 cm. cell. In normal rocks the amount of aluminium present in, say, 1·5 grams, is so great as to produce a slight but definite shift of the calibration graph; an increase in accuracy is therefore obtained by establishing for the aluminium-containing fraction of these materials a separate calibration graph using adequate amounts of the aluminate solution mentioned in the first part. In using this solution only the NaOH content exceeding the NaOH required to form the aluminate is allowed for in the final adjustment of the alkalinity. To recover any beryllium which might be occluded with the iron hydroxide residue, this residue is dissolved in 2 mls. 8N sulphuric acid and reprecipitated with 5·4 ml. 5N NaOH, filtered or centrifuged, washed, the alkalinity adjusted if necessary, and the beryllium measured, the result being added to that of the first fraction. For work of great accuracy this procedure should be repeated, since there is a tendency of beryllium to be occluded by iron hydroxide; it is, however, possible to recover very satisfactorily by the above procedure amounts of —e.g., 10 to 30 micrograms of beryllium in the presence of 1,000 times as much iron.

These investigations were made in the laboratories of Messrs. International Alloys, Ltd., and we wish to thank the directors of this company for permission to publish. We furthermore express our thanks to Mr. W. C. Johnson, of Messrs. Hopkin and Williams, for synthesising and supplying the dye, and to Mr. E. P. Bottley for supplying many of the minerals used in this investigation.

Weldable Hard Metals

DURING recent years considerable attention has been given in this country to the reclamation of worn components. One of the methods employed is that of building up the part by welding on a hard alloy in the manner described by Mr. Pocock in our last issue. It is apparent that the advantages of this process are also appreciated in Germany, where, according to published information,[1] high-quality built-up welding has become important, within the last few years, because with it worn tools can be repaired quickly without replacing the whole tool, thus saving time, money and valuable material. Furthermore, the wear-resistant parts of new tools or new machines can be made of high-quality built-up welded material which can be subjected to wear

The chemical composition, maximum hardness and properties relating to wear of the hard metals used for built-up welding are given in Table I. They are divided into three groups :—

TABLE I.
HARD METALS FOR GAS WELDING.

Group.	Chemical Composition.						Rockwell-C Hardness of the Built-up Weld.	Properties of the Built-up Weld.
	C, %	Mn, %	Cr, %	W, %	Co, %	Fe, %		
1	4·5	6·5	34	—	—	55	57	High resistance to wear.
	1·2	—	28	4	65	2	45	Great toughness and high resistance to corrosion.
2	2·2	—	24	13	59	2	52	Medium hardness at corresponding toughness.
	2·5	—	31	18	47	2	58	Normal hardness.
	2·6	—	31	23	42	2	62	Maximum hardness, but inferior toughness.
3	1·5	—	25	3·5	34	36	46	Great toughness and good resistance to corrosion.

The Chromium-manganese-iron Alloys.—These alloys are suitable as armour for rock drills.

The Chromium-tungsten-cobalt Alloys.—These constitute the so-called Stellite group; they are the most important alloys, and the most frequently used in engineering. Several degrees of hardness are produced in the range between 43 and 62 Rc, and to some extent the hardness can be influenced by heat-treatment. Schmidt, Lamarche and Kauhausen[2] as well as Cornelius, Trossen and Schmidt,[3] have proved that continuous heating at 800° C. may result in an increase of hardness of 2 to 9 Rc, but this is probably of no practical consequence. Variations in hardness may also occur because of melting and mixing with the supporting metal. In addition, the combustion products of the gas burnt may have an effect.

The melting temperatures of the alloys are between 1,200° and 1,330° C. Their hardness decreases slowly at 500° C. and drops more quickly at higher temperatures; the coefficient of thermal expansion is about the same as that of steel (see Table II). This fact is of great importance for the durability of welded material on components that are exposed to heat.

TABLE II.
MEAN COEFFICIENTS OF THERMAL EXPANSION
($\times 10^{-6}$.)

Temperature Range, °C.	Hard Metal.	Carbon Steel Containing 0·5% C.	Austenitic Steel Containing 18% Cr, 8% Ni.	Austenitic Steel for Valve Discs Containing Cr, Ni, W.
20 to 100	11 to 13	10 to 12	15 to 17	—
20 to 500	13 to 15	13 to 14	18 to 19	—
20 to 700	14 to 16	14 to 15	—	—
20 to 900	15 to 17	—	—	19 to 20

Cobalt-tungsten-cobalt-iron Alloys.—These have recently been developed in an effort to substitute tungsten and cobalt, which are in short supply, by more readily available metals. As a result of investigations by Cornelius[3] and by Schmidt, Lamarche and Kauhausen,[2] into this problem, such alloys were produced, one of which is given in Table I. Almost equivalent to the hard metal without iron content is an alloy containing iron, together with 4–5% molybdenum, 3–5% tungsten, 19% cobalt, and 30% chromium.

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1 F. Rapatz, W. Hummitzsch. "Schweissbare Hartmetalle," translated from abstract *F.D.I. Zeitschrift*, vol. 86, 1942, pp. 183–184.

2 M. Schmidt, W. Lamarche, E. Kauhausen. *Arch. Eisenhüttenw*, vol. 14 (1940-41), pp. 357 to 362.

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Cæsium and its application to Photo-Electric Cells

By A. G. Arend

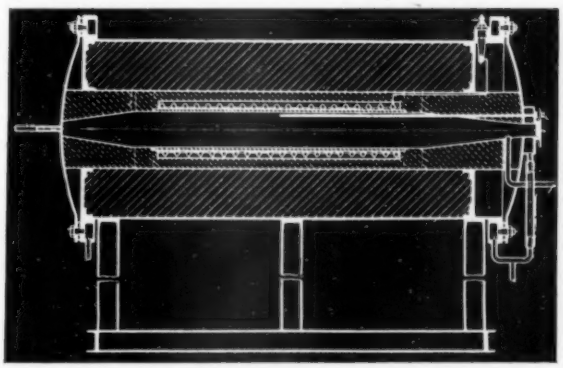
Discovered in 1864 by F. Pisani, cæsium has had no industrial application until recently, when important uses were found for it in the construction of photo-electric cells. The fact that it is considered to be the most electro-positive of all metals may open up new uses. Here, the extraction process is outlined and attention is directed to the use of the metal in photo-electric cells.

CÆSIUM represents one of those metals which, in former years, was described as a " rare " element, and secondly, as one which had no commercial value. To-day, however, it is generally recognised that cæsium is not, strictly speaking, a rare metal as it abounds almost everywhere, although in very small quantities, and, secondly, has found important uses in the construction of photo-electric cells. The fact that it is the most electro-positive of all metals may yet give rise to its application to a number of extraction processes which, hitherto, have not been tried. It is perhaps a coincidence, but it happens that the rarer metals generally appear to be located either as strongly electro-positive or strongly electro-negative in respect of electrolytic solution pressures, while the commoner metals take an intermediate course. There is little doubt that the present high cost of cæsium would tend to retard interest, but if in the future it was recovered economically it could be applied to numerous processes.

In a like manner the hydroxide of cæsium is the strongest base known, although, like the metal itself, this fact does not appear to have so far been taken advantage of to any extent industrially. A study of early literature will reveal that cæsium was the first metal to be discovered with the assistance of the spectroscope, where it is distinguished by two bright blue lines in the spectrum, and it is perhaps a record that in all these intervening years so little has been done in the way of utilising the metal. A study of the composition of mineral waters obtained from German sources will reveal the presence of this element in the natural product, but when preparing these beverages artificially, cæsium was omitted.

The need for numerous separations in the initial recovery of the metal appears to have done much to detract interest, but as so many industries to-day take advantage of the automatic means of control instituted by the use of the photo-electric cell, these have recently been given the closest scrutiny. At the outset it should be understood that cæsium is found in the potassium group during ordinary analytical practice, which means that although minerals of a complex variety have to be tackled, much of the initial group separations can be omitted.

As with other metals of what are termed the " rare " groups, anything in the nature of a large precipitate requires to be examined and frequently re-precipitated to ensure that no traces have been mechanically carried down. All kinds of silicates, including the commonest micas and feldspars, contain a minute percentage of cæsium, but tests made almost entirely relate to the use of the spectroscope. The extent to which this can nowadays be developed with the assistance of the modern spectrograph remains to be seen, but the precision with which the familiar blue lines appear in the ordinary spectrum makes the isolation of the metal relatively simple, even to the beginner. The metals with which it is associated are potassium, aluminium, lithium and rubidium, and in nature it appears to replace potassium in different feldspars and micas, and also rocks which contain these minerals. Although the testing is both rapid and simple, the recovery of the metal is more complicated, and resolves itself into a combination of what might be termed analytical methods on a large scale followed by electrolysis. Insofar as ordinary analysis is concerned, the proportion of cæsium is too minute for it to be isolated, and chemical reactions are only of value with those rarer minerals, such as pollucite, which contain an appreciable amount of cæsia. This relates to reactions such as antimony-trichloride addition-products, which separates cæsium from potassium and rubidium, and tests such as these applied with platinum chloride and tartaric acid, etc.



Showing the type of small hearth wherein the cæsium-bearing material is maintained at controlled heat until rendered soluble.

The Initial Extraction Process

The work of recovering cæsium is advantageously applied where associated processes are connected with the platinum industry, since the procuring of much of this metal in the ordinary way is expensive, and where the platinum is on hand in any case, the regeneration of the salts of this metal is a matter of ordinary routine. The chloroplatinate of cæsium is the least soluble of the

three metals precipitated by this reagent, namely, potassium, rubidium and cæsium, and with minerals which contain only a relatively small percentage of potassium, which, however, assists the complete separation of the cæsium, a comparatively rich precipitate is obtained at the commencement for subsequent separation. When lithium is also present this metal is occluded in the precipitate. This more or less simple method of directly getting at the cæsium cannot be followed elsewhere, and hence recourse has had to be made to alternative processes. Where initial tests have revealed that the metal is present in more than usual proportions, and sufficient to justify extraction, efforts are made to see what can be done about economising in the original solution of the material.

It is known that specialised methods of fusing, or smelting, have made it possible to get an initial concentration from the large bulk of silica material, but details at the moment are not obtainable, although these appear to be on the same lines as with the concentration of other metals of the rare alkaline-earth group. At the commencement the selected material was originally mixed with approximately six times its weight of sodium carbonate, with or without the addition of a small proportion of sodium peroxide, and fused in an iron crucible. This had then to be digested in a solution of 2% sodium carbonate solution to leach out the soluble contents, after which the resulting solution had to be evaporated to dryness with a large excess of hydrochloric acid to separate out the silica. Even by this expensive method of working the extraction was by no means complete, and although it sufficed for purely analytical purposes, it was too costly for large-scale application. During analysis the silica residue requires a further fusion with sodium bisulphate, or hydrofluoric-acid treatment, etc. Many of the earlier analytical methods described were only of practical value for the purposes of making determinations, and not for extraction on a larger scale. A much more economical method took advantage of another early method which was adapted to suit modern conditions. In all pyro-metallurgical methods, the greatest care has to be taken that temperatures rising much above a red heat are avoided, as otherwise the cæsium would be volatilised. (It is this latter feature which is taken advantage of in the specialised fusion method referred to, but which, so far, does not appear to have been divulged.) The following mixture which was successfully used comprised 20% of the cæsium-bearing silicate mineral, 66% lime, and 14% calcium chloride. This mixture requires to be intimately mixed and spread over a hearth so that it receives an even distribution of the heat, which has to be varied from time to time to maintain it within the desired red-heat limit, which approximates to between 800° and 900° C. Should the ignition cause the mass to fuse it would tend to adhere to the lining, and further, would cause a direct loss of cæsium, which appears to have a propensity to migrate in this manner. What cæsium is present is converted to chloride, but the reaction is not as simple as it looks, as it is an easy matter for the reverse action to take place, and the period of heating has to be timed according to the weight of charge dealt with. When cold the finely pulversied mass is digested in boiling water and filtered off, and the spectrum of the insoluble examined, while the solution is evaporated until crystals begin to form, cooled, and an excess of sulphuric acid added. The evaporation is then continued, and the mass baked until all fumes of hydrochloric acid have been removed. Although digesting this residue with hot water leaves the bulk of the calcium sulphate in insoluble condition, part of it passes into solution, and hence requires to be completely separated out. The solution contains besides the alkali metals, lithium, rubidium and cæsium ; and it is at this point that, where platinum is available, a direct separation can be made, although, as remarked, this is usually a limited activity.

Separation and Conversion to Metallic Cæsium

At this stage the solution is made strongly acid with hydrochloric acid and treated with a solution of antimony trichloride, from which the cæsium separates out alone as a white crystalline precipitate. There are different adaptations of this process, which are necessary, particularly where sodium salts predominate, details of which have been described elsewhere ; but one advantage of the system is that comparatively strong hydrochloric acid can be used as the washing medium, which, of course, necessitates the use of filters made for the purpose.

The antimony present in the precipitate has first to be separated by the familiar sulphide precipitation, after which it is converted to the trichloride for further use in succeeding solutions. The cyclic nature of this process will be appreciated, while the costs are relatively low, since the total sulphuric acid used is for precipitating only that part of the calcium salts which are soluble. Neither rubidium nor potassium are precipitated by the antimony trichloride, while provision is made to keep the lithium chloride soluble. In comparison to some of the rarer metal separations, this process is direct, but where a great predominance of alkali-salts is evident for a small cæsium content, it is advisable to carry out some preliminary crystallisation.

It should be mentioned that the amalgamation process for forming an amalgam of cæsium using electrolysis was tried out, and for simplicity a small mercury cell previously engaged for alkali-chlorine purposes was employed, using an electrolyte of cæsium chloride in place of sodium chloride. With mercury as the negative pole cæsium amalgam is formed, and which decomposes in cold water, forming the hydrate, and leaving the mercury intact for further use. Attempts at directly converting this to metallic cæsium were not successful, although it was considered that with more experimentation this might also have been achieved, as appears to have already been carried out with potassium. For this reason the earlier electrolysis of the cyanide was followed under improved conditions taking advantage of the vast amount of information which was available on cyanide reactions.

(Since the development of gold cyanide processes, it is doubtful if the salts of any other individual organic acid have been investigated as fully as those of hydrocyanic acid.) The cæsium chloride is converted to cyanide, which latter is pulverised and mixed with barium cyanide in the proportions of four of the former to one of the latter. It is not necessary to have a regular electric furnace for this work, as the mass can be raised to the fluid condition with the application of gas-heat.

This is preferably performed in a crucible of neutral refractory material, but with contacts fitted for the subsequent application of the current. Where the mass

has to be fused entirely electrolytically complications tend to set in, as that part nearest the electrodes decomposes first, and the subsequent action becomes intermittent, whereas with the molten material the reaction appears to be both more definite and more consistent. Current is applied at the rate of 19 amps. per sq. in., although the most suitable anodic current density appears to vary and has been applied at a higher figure. The result is that cæsium is deposited under a layer of fused material, but mostly in the form of globules, which are then warmed under petroleum and removed in this manner.

Conclusion

In conclusion, cæsium in many respects resembles potassium in that it is soft, burns easily in air, imparts a violet colour to flames, decomposes water with ignition of hydrogen, and melts at an exceedingly low temperature. Its function in the photo-electric cell is important at the present time, which, instead of being dependent upon sensitivity to white light, can be actuated by ultra-violet and even infra-red rays, using this medium. It has a competitor in the thalofide cell, where the oxy-sulphide of thallium is used, but functions in a slightly different manner. These specialised cells are utilised for night-signalling and other purposes of the kind, apart from all kinds of industrial control purposes which demand being kept within close limits of accuracy. In short detail, the cathode of one of these cells comprises an exceedingly thin film of cæsium deposited on a suitably prepared silver conductor, while the anode is represented by an open wire framework. Although, as yet, the demand is still a small one, the importance of cæsium should not be under-estimated, as it is also used for spectrum tubes with metal vapours of the cæsium-helium order in different patterns, and its salts for forming marked crystalline structures, for microscopical investigations, and for medical researches. With temperature control units photo-electric cells were previously inaccurate where a noticeable change in the light was observed during different parts of the day, and which necessitated an hourly adjustment. This was later improved on by the introduction of a special glass filter of an opaque make, which afforded almost 100% absorption. With the modern cæsium emissive cell, which has a peak output approximating to 15·000 Angstrom units, this filter can be superimposed between the object being heated and the cell, whereby, although the external light changes, there is no need to make adjustments of the control unit. The use of these cells for accurate temperature indication for forging, extrusion and casting purposes is already considerable, but it is expected that in the near future the demand will be vastly increased.

Wear Phenomena through Rubbing Friction without Lubrication

EXPERIMENTS were recently carried out on the wear-testing machinery developed by the official laboratory (Materialpruefungsanstalt) at Stuttgart with ring-shaped test-pieces of different materials and of steel St. 60[2] for the purpose of comparison. It was shown that relative rubbing of metallic workpieces without lubrication results in three different types of wear, causing different appearance of the surfaces in contact. These kinds of wear are : Metallic wear without cold-working, metallic wear with cold-working, and oxidation wear.

Metallic wear without appreciable deformation (Type I) occurred when normally tempered test-pieces of steel St. 60 were running against pieces at similar material, such as tempered steel St. 37[3] or St. 60 at low pressures ($p = 30$ lb. per sq. in.) and speeds ($v = 100$ ft. per min.). The wear occurred with a grinding sound, and grooved wear faces resulted (Fig. 1). The volume worn away in the unit of time is large and does not vary with different speeds.

Metallic wear with considerable deformation (Type II) was observed when steel St. 60 was running against

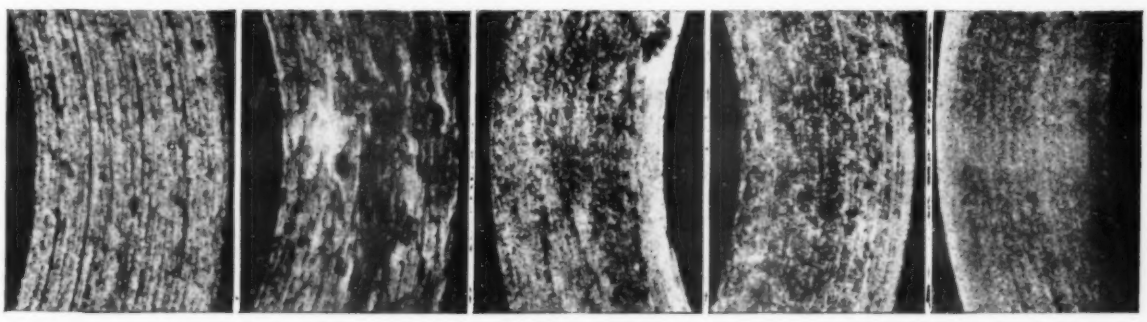
Fig. 1.—Surface of contact of Steel 60 after running against Steel 60. Surface of contact considerably roughened and grooved.

Fig. 2.—The surface of contact of the aluminium alloy is upset and covered with bright shining spots.

Fig. 3.—The surface of contact of Steel 60 is completely covered by aluminium alloy.

Fig. 4.—The surface of contact of cast iron is somewhat roughened and reddish brown with bright shining concentric rings.

Fig. 5.—The surface of contact of Steel 60 is reddish brown and shining.



softer metal, such as copper, tin or aluminium. After a short run, cold-worked areas appeared on the wear face of the softer components (Fig. 2). The development of these areas was facilitated by high pressure and increased speed. At the same time, the surface of contact of the harder steel counterpart was covered with metallic material rubbed from the softer test-piece (Fig. 3). The grinding sound of the rubbing action developed into a rattling noise and at the same time the wear decreased.

Oxidation wear (Type III) was observed when steel St. 60 was used as test-piece and harder material as counterpart, such as cast iron, especially chromium steel, tungsten carbide (Widia), and steel with chromium-plated or nitrated surface. Oxidation wear faces (Figs. 4 and 5) appeared and loose oxidation particles were generated in very small quantities. This process, which could be recognised already by a shrill whistling noise, took place only at lower pressure and by using correspondingly harder counterparts or by applying oxygen or air rich in oxygen. One of the used test materials at least had to show a certain resistance against the abrading of particles from its surface, either because of its hardness or on account of cold-working during wear, as, for example, hard manganese steel.

The occurrence of one or more of these phenomena depends on the hardness properties of the test-pieces and on other conditions. Change of pressure results in proportional change of wear only as long as one kind of wear does not develop into another kind. The decrease of wear with increasing speed is caused by a change in the kind of wear—i.e., the change from metallic to oxidation wear.

When a pair of Steel-60 test-pieces was used the wear could be decreased considerably by a preceding cold-working of one test-piece (by upsetting or surface compression). The preceding cold-working of aluminium, however, did not affect its wear appreciably. The use of gases instead of compressed air with a pair of steel-60 test-pieces resulted in a decrease of wear down to one-fifth (when N_2 was used) and $\frac{1}{10}$th (when O_2 was used). There was very little influence of the humidity of air on the wear in the investigated range from 50 to 100% relative humidity.

The purely mechanical conception of the wear action is very helpful in explaining the wear phenomena. The harder material acts on the soft surface like a file. The experiment carried out with upset material and at increased pressure shows that the working capacity and the work-hardening properties of the test materials influence the wear. The tests with different gases show that the wear cannot be of a purely mechanical kind, but that chemical actions also contribute to the result.

1 E. Siebel u. R. Kobitasch, "Verschleisserscheinungen bei gleitender trockener Reibung," Berlin, 1941. Abstracted in *V.D.I. Zeitschrift*, vol. 86, 1942, p. 157.
2 Steel 60 has a tensile strength of 38 to 45 tons per sq. in.
3 Steel 37 has a tensile strength of 23·5 to 29 tons per sq. in.

The Nickel Bulletin

THE April issue of the *Nickel Bulletin* includes abstracts on the electrolytic polishing of metallographic specimens, the influence of cobalt and nickel oxides in enamelling, black-nickel plating, the influence of alloy elements on hardenability, and the spot-welding qualities of aircraft steels.

Copies of the *Bulletin* may be obtained, free of charge, from the Mond Nickel Co., Ltd., Grosvenor House, Park Lane, London, W.1. Individuals are asked to give the name of their firm or some indication of their special interest.

1943 Minerals Production in U.S.A.

THE quantity of minerals and mineral products produced in the United States in 1943 exceeded all previous records.* Here are some year-end estimates taken from the U.S. Bureau of Mines report :—The physical volume of U.S. mineral production in 1943 increased approximately 3% over that of 1942. In the metals groups, outstanding gains were registered in aluminium and bauxite, beryllium, magnesium, tantalite-columbite, and titanium ; small to moderate gains were recorded for cadmium, chromite, copper, ferro-alloys, pig iron, manganese ore and mercury production ; and declines were noted in gold, silver, iron ore, lead, molybdenum, nickel, tellurium and zinc.

In the fuels group, small gains were made in bituminous coal and coke, and greater gains in petroleum, natural gas and natural gasoline and liquefied petroleum gases. There was virtually no change in the production of anthracite. Of the other non-metallic minerals, crystalline graphite, potash, phosphate rock, magnesite, sheet mica and salt showed marked increases, whereas cement, sand and gravel, clay products, gypsum, slate, sulphur, stone and vermiculite experienced sharp decreases.

Production of primary aluminium increased more than 75% from 521,106 short (472,747 metric) tons in 1942 to about 920,000 short (835,000 metric) tons in 1943. By the last quarter of the year, aluminium was being produced at an annual rate of 1,128,000 short (1,023,000 metric) tons. Domestic production, together with imports of aluminium from Canada, were more than adequate to meet essential requirements during 1943. Domestic production of bauxite increased from 2,768,343 short (2,511,441 metric) tons to 7,166,000 short (6,500,000 metric) tons by far the largest production in history, and imports of South American bauxite reached the record total of nearly 1,500,000 short (1,360,000 metric) tons. The bauxite supply greatly exceeded requirements and stock piles of more than 4,000,000 short (3,600,000 metric) tons were accumulated. Alumina plants treated material higher in silica than in previous years, due to additions of lime-soda-sinter equipment at several plants. Domestic production of bauxite was sharply reduced during the fall to rates more nearly in balance with consumption.

Production of magnesium increased from 47,420 short (43,019 metric) tons in 1942 to about 185,000 short (168,000 metric) tons in 1943, nearly 30 times as much as in 1940. The supply of magnesium exceeded consumption during 1943 and industry stocks increased.

Mine production of lead and zinc decreased in 1943, and copper production was only slightly increased. Smelter production of copper from domestic ores increased slightly from 1,087,991 short (987,025 metric) tons in 1942 to about 1,090,000 short (990,000 metric) tons in 1943. Production of refined lead declined from 467,367 short (423,995 metric) tons to about 425,000 short (385,000 metric) tons and slab zinc declined from 629,957 short (571,497 metric) tons to about 585,000 short (530,000 metric) tons.

Mercury production in 1943 advanced about 2,700 flasks over the 50,846 flasks produced in 1942, and represented the highest annual output since 1881. Mine production of antimony was nearly double that in 1943, and substantial gains were recorded in cadmium and beryllium.

* *Chemical Industries*, January, 1944.

The Future of the Aluminium Industry

By W. C. Devereux, F.R.Ae.S

Chairman and Managing Director, High Duty Alloys, Ltd., Magnesium Castings and Products, Ltd. Chairman: International Alloys, Ltd. Director: Reynolds Rolling Mills, Ltd., etc.

The author deals with some aspects of the British aluminium industry raised by our Special Contributor, published in our March issue (p. 231). He emphasises the need for an early statement, by a responsible authority, on the possible post-war reductions in the price of aluminium alloys, and suggests that they could be given in terms of pre-war values. Many other questions are raised in an effort to determine how the British industry is likely to stand in relation to the industries of other countries and to emphasise the vital importance of a large and highly developed aluminium fabricating industry in the country. The views of Mr. Devereux were submitted to our Special Contributor whose comments are appended.—(Editor.)

THE achievements of aluminium and its alloys in this war, chiefly as the principal material used in the construction of the high performance aircraft and aero-engines, which to-day represent some of the highest achievements of efficiency in modern engineering, have led engineers in all industries to examine very closely the possibilities of exploiting the many advantages in their own designs.

The decision to change over to a new material is not one to be taken lightly. The younger industries, such as those of aircraft and automobile manufacture, have grown up with aluminium and have learnt by experience slowly and surely collected, how the light alloys behave in their own particular machinery. On the other hand, owing to the interruption of the normal production of a number of industries, including many of the older ones, designers are being urged to produce post-war designs, utilising light alloys in place of ferrous, non-ferrous metals and alloys, wood and other materials which they used before the war and which they know so well.

The light alloy industry, which has grown up with a background of scientific research and control has been apt to underestimate the difficulties of engineers in designing for the use of the new high-strength light alloys. The properties of these alloys under a very wide range of conditions are established with all the precision that modern experimental testing technique can achieve. What, then, is the difficulty of redesigning for the new materials on the basis of experience with the old? The answer, of course, is that few of the well-established engineering designs were worked out from first principles. Most of them represent years of development by trial and error methods—squeeze a little more power out of this—failure—thicken up this section—try again, and so on, and although the properties of light alloys are readily available, this is not always the case with the materials used hitherto, so that one side of the equation conversion is incomplete.

Few engineers are fortunate enough to be concerned with the question of producing the most efficient designs from a purely technical point of view. There is another equation which is just as much a question of efficiency, and the present position in regard to this equation is almost exactly the reverse of our previous purely technical equation. The missing factor is the post-war price of aluminium and its alloys in the form of finished engineering components.

The potential users of light alloys have studied the comprehensive figures for the properties of light alloys which have been sent them and have started to work out their new designs based on these materials. They have then inquired what will be the cost of the advantages which they have found can be achieved, and they have been brought up sharply by the contrast between the precision of the technical information given them and the vague and airy statements concerning post-war prices.

They have been told that the output of aluminium has increased vastly during the war and that there must therefore be a reduction in price. They may also have been reminded that in the U.S.A. the price of virgin ingot has been reduced during the war from 20 down to 15 cents per pound. Many, however, have pursued the matter further and have asked for an estimate of post-war price *in this country* for a specific light alloy component, and here they have found themselves confronted by a profound vagueness.

It would not, in my opinion, be indiscreet and certainly not impossible to state now, *in terms of stated pre-war values*, what reductions in price it would have been reasonable to expect if those values had not been upset by the war.

The Canadian producers have already stated that they can make primary aluminium ingot at a cost which would enable it to be sold *in this country* for about £55 to £60 per ton at *to-day's* values and rates of exchange. This is a very important statement—it means, in fact, that primary aluminium could be available at *half* the present controlled price and almost half of the pre-war cartel price.

Thus, we have most definite information on Canadian price, and we already know that they have capacity for producing 500,000 tons of aluminium—about the total world production in 1939,—and we know that this country was the principal consumer of Canadian aluminium before the war, and still is. On the other hand, we have been told nothing about the present output of producers in this country, let alone their probable post-war prices.

Is it too much to expect, to be given figures for this country's aluminium production which may be compared with those which have been made available to us by the Canadians?

This is a vitally important matter, for there has been built up in this country a very large and highly developed aluminium fabricating industry which is second to none

in technical ability and is surpassed in capacity only by the United States industry. This industry employs many thousands, and whether or not it will be able to continue to utilise its present capacity after the war and continue to employ all those workers, depends almost entirely on the question of the price of its products relative to those of other engineering materials. It is time, therefore, that the vital facts should be made known, so that the industry can plan the post-war situation.

The absence of information regarding post-war prices does not of course prevent us from making our own estimates, and as I see it, this country cannot produce aluminium by the existing processes at a price which can compete with Canadian aluminium, in fact I will venture to suggest that the premium on home-produced aluminium will be as much as 25%.

This situation, if correct, immediately raises some very delicate problems involving the plans of the British and Canadian producers and their respective Governments.

The following are some situations which will arise :—

(1) Canada has a very large capacity for producing cheap aluminium and domestic markets for only a small proportion of that capacity. So far, Great Britain has taken a large proportion of her output.

(2) This country has fabricating and engineering industries which could absorb a large proportion of the Canadian output.

(3) The producing capacity in this country cannot supply the quantity of aluminium required to utilise our fabricating capacity. With the present capacity the price cannot be brought down to that of Canadian aluminium.

(4) The extent to which the fabricating capacity can be utilised depends to a large extent on the price of aluminium.

So far, only the price of primary aluminium has been discussed. From the point of view of the user of light alloys this is not the real answer to his problem—what he really wants to know is the price of finished components relative to that of similar items in other materials. Naturally, he expects a considerable reduction in fabricating costs, since the industry has been increased greatly in plant capacity and under the pressure of wartime needs efficiency of both machinery and operation has been very greatly increased.

Every engineer will appreciate, however, that to take advantage of the economy of high production machinery and practice you must have high production. This is where we start going round in circles. It has already been stated that the proportion of the fabricating capacity which can be utilised depends on the selling price of its products, and also the prices of primary, secondary and scrap aluminium. These factors are doubly important, because the fabricating industry has to allow for a considerable charge for aluminium which is absorbed in its processes, part of which is lost in the form of melting and other process losses, and the remainder, a large proportion, goes back into later production as secondary, bearing additional costs of remelting and refining.

This extremely complex problem then resolves itself as follows :—

(1) The extent of the post-war markets after the war, and thus the amount of employment which can be offered by the fabricating industry, depends on the price of aluminium components.

(2) The price of aluminium components depends partly on the price of primary aluminium and partly on the proportion of the capacity of high production equipment which can be utilised, and thus on the content of markets.

In other words, we shall just go round in circles unless some fixed point can be established. The obvious starting point is the price of primary aluminium produced in this country since, as there can be little doubt that the limited capacity of British producers can be fully absorbed, the market factor, which complicates the calculations of the fabricating industry, does not arise. Armed with this and the Canadian price, and, if possible, with information regarding the Government's attitude to the question of covering any discrepancy there may be, the fabricating industry and the users could work out price and markets.

As a fabricator, I have gone so far as to state that if primary aluminium were available at a price of 6d.–6½d. per pound, as quoted by the Canadians, and if a sufficiently large proportion of our present fabricating capacity will be absorbed, then we might expect a reduction of up to 25% in the fabricating costs in terms of pre-war values. Combined with the reduction in price of Canadian aluminium, this might result in a reduction in price of fabricated components of between 25 and 30% which, if the figure could be presented as reasonably certain, might well enable the designers to lay such definite plans as to give a fairly definite idea of the probable extent of post-war markets.

The whole of the light alloy industry is rapidly approaching a fork in its road of progress. One way leads to unprecedented opportunities for greatly increased markets by way of the incorporation of light alloys in the new and improved designs which must be made for post-war products. The other way leads back to the 1939 scale of production and to wholesale closing down of the great new fabricating plant built by the toil and sacrifices of our people.

Correspondence

The Editor, METALLURGIA.

Dear Sir,

I was interested in the comments of Mr. Devereux on my views concerning the future of the aluminium industry in your March issue, and commented upon in the correspondence published in your April issue.

There is no doubt that the American-owned reduction plant at Arvida in Canada can produce at a much lower figure than the British Aluminium Co. The production of the latter is small as well as costly, and their policy, therefore, would most naturally be in the direction of maintaining, by some means, a monopoly in their home market in this country. The British Aluminium Co.'s output could be absorbed in this country even if the demand for aluminium after the war is restricted, and Mr. Devereux is obviously afraid of such a tendency.

So far I agree with Mr. Devereux, but what he skilfully conceals is that even with metal at present cost, the prices for wrought aluminium alloy products are far too high. Take as an example a medium gauge Duralumin sheet at 2s. 6d. per lb. The present metal cost, including melting loss, would be a generous maximum of 10d. per lb. The actual rolling and heat-

treatment cost, in an efficient mill, would be less than 5d. per lb.

Using relatively inefficient machinery, the rollers before the war were able to sell pure aluminium circles to the hollow-ware trade at below 1s. per lb. With modern machinery and using an alloy composed of 50% scrap and 40% virgin aluminium at 6½d. per lb., medium gauge Duralumin sheet could be produced to-day at a cost approximately the same as that for the pre-war hollow-ware circles.

This aspect of the price policy of the wrought alloy trades is really quite as important as the price of primary metal, when the future of the whole industry is under consideration. The conditional offer made by Mr. Devereux of a 30% reduction in his prices needs to be nearer 50%, even to begin to look attractive to, say, the motor manufacturers or shipbuilders.—Yours sincerely,

YOUR CONTRIBUTOR.

London, W. 1,
May 6, 1944.

Erratum

In the correspondence on page 293, the first paragraph commencing on the right-hand column should read: Fortunately for our industry as a whole, but equally . . ."

Finishing Processes Employing Abrasives

Investigations on various metal finishing operations have been carried out in Germany[1] *in an effort to find a clear definition for such methods as lapping, honing and superfinishing, and thus to reduce misinterpretation. The results are presented in this article.*

IN order that definitions, which stress the essential differences between various finishing methods, can be formed, investigations have been carried out on such methods as "lapping," "honing," and "superfinishing." Each method is considered separately, and the results will have a wide interest.

Lapping

The designation "lapping" has been used in workshops both here and abroad for methods which are actually quite different in principle. Consequently it was by no means easy for a technical committeee established for this purpose[2] to lay down a clear definition which would correspond as far as possible with its use in workshops and yet stress simply and clearly the specific characteristics of the process. In other countries, too, the use of the word "lapping" for quite different operations has also led to misinterpretation, but no attempt to find a clear definition has been made.[3]

After careful consideration of all points of view, the Committee decided on the following definition of lapping:—

> "Lapping is a production method, in which the workpiece and the tool glide along each other without positive guiding. A loose abrasive is used, and the direction of attack is constantly changed. The shape of the tool face and the movement of the tool should be so chosen that the ideal form of the tool is retained as long as possible in order to produce the maximum of workpieces with a geometrical form approaching the ideal. By this method, suitably prepared workpieces may be finished to high accuracy in geometrical form and with high quality of surface finish. At the same time, the dimensions can be kept within close limits."

This definition is based on the following considerations:—

1. A lapping operation is usually provided only if the workpiece is required to have (*a*) high accuracy in geometrical form; (*b*) dimensions within very close limits; and (*c*) high surface quality. This sequence also indicates the relative importance of the conditions in a lapping operation.

2. There are many processes which make use of loose abrasives without being lapping operations—for example, mopping, buffing and polishing. The proposal to designate as "lapping" every grinding method which makes use of loose abrasive, presumes that the abrasive grain is not held rigidly during the operation, but has a planing effect produced by a "rolling" action between the workpiece and the tool. This assumption is disproved by Figs. 1 and 2, which clearly show the formation of chips by the grains.

Workpieces which have to be in conformity with the above-stated conditions may be economically produced on lapping machines which have two horizontal discs, usually made of cast iron, and which revolve at different

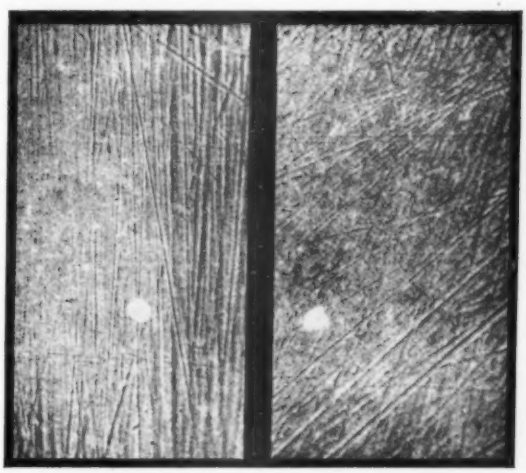


Fig. 1.—Surface of an unused gauge block of highest accuracy produced on the lapping machine without any finishing by hand.

Fig. 2.—Surface of an unused gauge block of highest accuracy, probably finished by final hand-lapping.

Chip-removing effect of the abrasive grains. Magnification × 730; reproduction, 9/10.

1 Die Begriffe. "Laeppen, Ziehschleifen und Feinziehschleifen."
2 Ausschuss fuer Feinstbearbeitung des Reichsausschusses fuer wirtschaftliche Fertigung-A.W.F.
3 See H. J. Wills. "Lapping for Final Finish." *Amer. Mach.*, N.Y., vol. 83 (1938), pp. 985–987.

speeds. The workpieces are placed between these two horizontal discs and are guided by a holder which corresponds in form to the workpiece and performs an additional reciprocating motion with an adjustable stroke in a horizontal direction.

The nature of the machine combined with the exactness and quality of the shape and surface of the workpiece, demand the use of a loose abrasive mixed with a suitable fluid and applied to the laps in a consistency suitable to the particular purpose in hand.

New Designations for Methods hitherto called "Lapping."—In addition to those already mentioned, two other operations were also formerly known as lapping, but these are quite different from machine lapping. The first of these operations, still frequently called "adjusting," as in the manufacture of plug gauges and snap gauges, is a finishing operation. The plug gauge is rotated slowly on a suitable machine and is worked with a flat bar of suitable material (cast iron, copper or zinc) and with loosely applied abrasive. Flat and snap gauges, on the other hand, are worked on a stationary or rotating disc, which is as near perfect flatness as possible, but otherwise the working conditions are the same. The operation differs from real lapping in that the results depend upon the skill of the operator, whereas the lapping machine, by virtue of its motions, produces exact shapes and dimensions automatically.

Another operation formerly called "lapping" is the fitting of components such as conical gauges, tubes, threaded arbors and rings, gears, and so on. These workpieces can only be lapped by means of a correspondingly shaped counter tool, or by means of the engaging faces rolling on each other, thus finding their proper level. This operation depends, even more than in the previous one, upon the skill of the operator who has to use discretion in exerting pressure and distributing the abrasive irregularly on the work. This method is adopted where the shape of the workpiece is such that the application of other methods is impractible.

One of the first suggestions was to call the three kinds of operations, lapping of the 1st, 2nd, and 3rd degree, but as this might lead to misapprehension about the quality of the process, the following designations were ultimately chosen :—

Machine lapping, as stated, is possible only on cylindrical, spherical and flat faces. This operation is called "lapping" without any further qualification and with the definition laid down above.

For the second kind of lapping, which, as stated, was frequently called "adjusting" in the gauge industry, the designation "limit lapping" (Mass-Läppen) was chosen, because the main purpose of the operation consists in finishing the workpiece to precise limits.

For the fitting of components such as cones, threads, gears, etc., the designation fit-lapping (Pass-Läppen) was suggested, because in it the workpieces are fitted to each other or to a master gauge. These designations should soon become popular, because they involve only logical modifications to the existing meaning of the expression "lapping."

The methods of making tool edges of hard metal and other tools with bonded abrasive wheels are frequently called lapping, but they are not strictly lapping processes, since no lapping motion takes place. They are really fine-grinding methods in that a grinding wheel rotating in fixed bearings is fed along a stationary workpiece. The fact that the abrasive chosen (aluminium, oxide, silicon, carbide, diamond, etc.) is frequently applied in powder form to a metal wheel, does not make it a lapping process.

Honing and Superfinishing

The Committee has suggested the following definition for honing (Ziehschleifen) :—

> "Honing is a method of rubbing a fine-grained bonded abrasive to and fro with a twisting motion, on a pre-machined surface of a workpiece and exerting the necessary pressure to produce a comparatively smooth, but not necessarily bright, surface. Up to 0·008 in. can economically be taken off the surface of the workpiece by honing, so that the marks of the preliminary machining can be completely removed. To achieve a macro-geometrical improvement in a surface, rigid tools have to be used."

For superfinishing (Feinziehschleifen) the Committee has suggested the following definition :—

> "Superfinishing is a method of moving a bonded abrasive to and fro, on a pre-machined face in the same manner as when honing, but with less pressure and less speed. A better surface finish results than that obtained by ordinary honing. To achieve macro-geometrical improvements in the surface, rigid tools have to be used."

Honing is used in industry, especially in the production of holes. It is perhaps not yet generally known that for macro-geometrical improvements of the surface rigid tools must be used. Superfinishing, too, is perhaps not as widely known in industry as it should be, and this is why a supposedly new method has been greatly advertised in recent years. This is the so-called superfinish method used in the U.S.A., which is considered to be similar to the super-finishing method given above, since all the characteristics claimed as special features, are also contained in the method described. The claim that an amorphous skin is removed by the superfinish method has not as yet been proved.[4]

4 See G. Schmaltz. *Technische Oberflaechenkunde*, Berlin, 1936, pp. 160–161.

Inauguration of Scottish Branch of the Institute of Physics

PHYSICISTS employed in industry in Scotland have for some time felt the need of local opportunities for the interchange of knowledge and experience of applied physics. At their request the Board of the Institute of Physics has therefore authorised the formation of a Scottish Branch of the Institute, which is to be centred in Glasgow.

The inaugural meeting of this branch took place on April 22, in the chemistry buildings of the University of Glasgow, at which Mr. E. R. Davies, F.Inst.P., a vice-president of the Institute, and director of research, Kodak, Ltd., delivered an illustrated lecture on "High-speed Photography and its Applications in Science and Industry." The meeting was both interesting and informative, and in view of the enthusiasm which prevailed there is every indication that this branch will be successful. Scottish readers who are interested should communicate with the acting honorary secretary, Dr. R. S. Silver, F.Inst.P., c/o Messrs. G. and J. Weir, Ltd., Cathcart, Glasgow, S. 4.

A Logical Approach to Metallurgical Treatment

By A. C. Vivian, B.A., D.Sc., A.R.S.M.

In a letter to the "Journal of the Institute of Metals," the writer has drawn the attention of metallurgists to the line of thought he started by a short publication in 1941, which was followed up by his much fuller suggestion as to how the mechanical properties of a metal could with advantage be viewed as features of its true stress-strain curve.† There is nothing original about this idea, though it need not be too lightly taken for granted that there is nothing fresh in the suggestion; in fact, the adopted view seems to share with discoveries the quality of applicability and usefulness in unforeseen directions. The writer believes that one of the least obvious of these directions concerns metallurgical treatment; and that, as a result of a renewal of interest in the mechanical properties of metals along the line of thought thus introduced, metallurgists might derive benefit. But, as possibilities of this kind are not altogether self-evident, the following article is his endeavour to point them out.*

MANY a philosophical essay would strike the practical man as an attempt to show how well the cart looks in front of the horse for the sole purpose of providing theorists with light entertainment; but it is believed that even the practising metallurgist may recognise potentially useful characteristics in the following arguments intended to emphasise the need for a more logical approach to questions of metallurgical treatment. Since the days of great activity in elucidating the meaning of the tensile test and fatigue failure, a comparative lull has settled down on the more public consideration of all such subjects, due possibly to the complacency of some and the perplexity of others. A few have proceeded further: their work arouses but minor interest, as so very few metallurgists can see any particular hope for the further development of treatment and alloys in a thorough-going understanding of the mechanical properties.

An analogy might serve to show how a more scientific comprehension of these reactions of the metals to loading could result in modified and amplified metallurgical technique.

The particular aim of the engine designer at some moment may be to obtain power. His "power" is known in terms of work and time, of which his "work" is unambiguously determined by swept cylinder volume, revolutions per minute, number of cylinders, heat cycle, and so forth. All these ingredients of power are perfectly understood: no improvement in this part of his technique could result from a further study of this ultimate aim.

On occasions, the specific aim of the metallurgist may be to procure proof resilience in a metallic material. He knows well enough that low elastic modulus and high elastic limit are its ingredients, and that certain other considerations of fatigue endurance and corrosion resistance are desirable secondaries for long service. In this case, then, the metallurgist can have but little to learn from a further study of the mechanical properties concerned—at least he knows just what he is aiming to get.

In cases of other special aims, however, the metallurgist's position would seem to be less satisfactory. The commonest, though not necessarily the most serious, risk is in his treatments to procure the mechanical property of hardness which are applied with no clear idea as to the ingredients of hardness, and without knowing for sure whether the indentation test measures the capacity for resisting wear, or whether hardness by one kind of test is strictly comparable with that by another kind of test. To this extent metallurgical treatment is seen to be arbitrary and empirical, even as the technique of the engineer would be if he found himself unable completely to assess the results of his designing for power from an understanding of the nature of power, and if he was thereby forced to rely to some extent on the empiricism of the test-bench to guide his groping mind. The laboratory for testing materials is the guide, in fact, upon which a great deal of the burden is being thrown like this by metallurgists, and the approach by such means is, in the sense above described, more empirical and not so scientific. Such an approach must also be illogical, whenever the aims of the treatment are not sufficiently understood, if the study of the aims is not being pursued down every avenue of research. A certain new line of thought seems capable of simplifying the understanding of hardness, and has recently brought into greater prominence some features of that property which may ultimately modify treatment.

Unfortunately, the terminologies of neither metallurgy nor strength of materials are all that could be desired: in consequence it is no easy matter to gauge the extent of the prevailing understanding of the means (the treatments) or the aims (the properties). On the one hand, for example, there is a latitude in the use of the expression "austenitic steel," which defies the differences in the treatments concerned, and baffles mutual interchange of ideas about the steels; on the other hand, the term "hardening" continues to be used even without intention to suggest the increasing of resistance to penetration, abrasion or indentation as a

* *Journal of the Institute of Metals*, October, 1943.
† "A Renaissance of Mechanical Properties," I. Mech. E., received Sept., 1942.
‡ "Fracture; the Distribution and the Sum of its Energy, and its Specific Energy." A. C. Vivian. (Shortly to be published by *Engineering*.)

direct aim of the process. Other "straws" in considerable numbers indicate the "direction of the wind": the prevailing lack of understanding on the subject of toughness has recently been exhibited in publications by reputable metallurgists. Therefore, if the principal object on any occasion were to procure in a material the important property of high reaction in the form of work—high unital energy to oppose fracture strain, or any other degree of plastic strain—it seems that very few practising metallurgists can possibly know how to measure it. Measurement of this ordinary toughness by the notched-bar test is out of the question; neither the area under the nominal stress-strain curve, nor the area under the true stress-strain curve (employing the usual conception of strain) is of the least use. In this case, a return to the study of the mechanical properties can show—in fact, has recently shown‡—the only method of measuring ordinary toughness.

What, then, of all previous treatments designed to procure this toughness? If the aim has been so little understood in the past that the only means of measuring it have been hundreds of per cent. wrong, the treatment can have been but groping in the dark calling out in vain for suitable testing methods! There, at least, the approach has been by empiricism, even by misled empiricism. The danger in this case has been the seriously misleading figures of toughness afforded by the areas under the curves hitherto employed, a much greater danger than that of accepting the "ultimate tensile stress" as the criterion of strength. In the absence of anything better, of course, all these nominal values of the properties, though wide of the mark, serve in conjunction with copious testing to enable the metallurgist to edge his way forward. But, if the past history of research is any guide, there seems to be little doubt that advantage to treatment is bound to be derived from the correct measurement of specific energy which yields values so different from those of the erroneous measurements.

Similarly, treatment is possibly due for modification and improvement as soon as the study of the difference between notch-toughness and ordinary toughness has shown what it is, on failing to quench certain steels after tempering, that makes for notch-sensitiveness with unimpaired ordinary toughness. If there is no determination on the part of metallurgists to discover above all things the parts or components of which hardness, toughness and notch-toughness are made up, it might be held that metallurgists are "putting the cart before the horse" in metallurgical research to procure the mechanical properties in metallic materials. A study of the mechanical properties involved seems to be the logical way of tackling such problems, though solutions may in the fullness of time be reached accidentally or by "trial and error" methods which are sufficiently lucky.

The great amount of philosophical and experimental work on fatigue endurance to-date was carried out in order to throw light on the nature of the mechanism of fatigue—to discover the components of fatigue loading. It can now be seen that metallurgical treatment has been modified critically by that work—firstly in the direction of providing corrosion resistance in metals to improve endurance; secondly, in order to avoid the production of alloys in which phase-junctions give rise to stress-raisers of the "inherent" type; and thirdly, in order to exclude from use (wherever possible) that kind of metallic base found to be intrinsically weak in fatigue endurance. But even nowadays the complaint is heard that, in some instances, the factor of safety found necessary to ward off fatigue failure must be put abnormally high; and in these cases the metallurgist must shoulder a share of the responsibility unless he is to throw the whole blame upon the designer for practice which does not seem to be blameworthy in the least. Researchers of the future may find themselves in a better position to comprehend what remains mysterious about fatigue if they would co-ordinate their ideas on the mechanical properties according to the fundamental considerations and the fresh line of thought recently found so helpful in the analysis of hardness and of toughness. Let the metallurgist turn once again to the mechanism of failure by fatigue loading, thus approaching the unsolved part of this problem by the scientific methods which have hitherto characterised this particular work. In attacking all problems in connection with the mechanical properties, in fact, let the metallurgist take as his model the philosophical and experimental research which has been conducted so assiduously in the past with demonstrably powerful influence upon metallurgical technique.

The new expectations in any reconsideration of the mechanism of loading possibly lie for the most part in a certain adopted, slightly orientated view of fundamentals. If, as it has been shown elsewhere, nearly all the mechanical properties of metals are to be read direct from the one true stress-strain curve which employs "differential" strain (instead of the usual conception of strain); and if the remainder, hardness, fatigue endurance and notch toughness are then seen to have relationships with the family which are already fairly clear and will soon be clearer still, it should then be seen that metallurgical treatments for procuring different mechanical properties in metals at will can be viewed quite reasonably as methods of altering the shape of the one true stress-strain curve. In answer to the question, "What metal's curve-shape is altered?" it would be natural to suggest that the metallurgist might go as far back to beginnings as possible, and claim that it is the single crystal of the pure metal which he is really modifying by treatment—whether by grain refinement, cold work, alloying by the substitution of foreign atoms in the lattice, or alloying by the substitution of foreign molecules in the lattice. Then there are the mixtures which are frequently prepared—alloys consisting of mixed grains, or of grains which consist of a mixture of phases—but these will not be found to present complications.

What, then, is the shape-change due to metallurgical treatment? The subject is in its infancy, and only the simple standard cases can be drawn upon with any safety just now. Perhaps the first complication is due to the fact that treatments which are now considered simple may effect more than one change at a time of the new kind to be considered, one masking or enhancing the other change. A well-known example of this is offered by the modification of the copper lattice by zinc atoms, when the expected effect of reduced ductility is masked by the simultaneous chemical effect of zinc in improving the ductility of the (literally impure) copper used in the preparation of brass. Again, when treatment by the substitution of foreign molecules is

carried out, there is always an overlapping effect of the substitution of foreign atoms at the same time ; and, as likely as not, yet another effect due to some change in grain-size. Somewhat similarly, there may be an overlapping effect of two distinct treatments when cold work not only produces the expected lattice destruction to 10^{-4} cm. crystallite size, but also gives rise to molecular precipitation, or substitution of foreign molecules in the lattice as well.

However, it seems fairly clear that, in the standard cases which may be valuable guides in the analyses of other cases, each treatment, suitably simplified by the elimination of incidental treatment, changes a logarithmic curve of long flat shape to a logarithmic curve of a shorter, steeper shape, whereby all those mechanical properties measured as stresses—strength, in fact—increase in value ; whilst all those properties measuring as strains—ductility or plasticity, in fact—decrease in value at the same time. Unless lattice-energy is somehow supplied or made available during treatment, and it seems that there are many ways of doing this, rise in strength should balance fall in ductility to give constant toughness. If some established treatment steepens the curve without a corresponding shortening, the increase in toughness must be due to additional energy having been made available to the lattice in some way. On the other hand, treatment may be the cause of loss of lattice energy, steepening being accompanied by more than the due amount of shortening : in this way strengthening is only effected with more loss of ductility than is normal, with a loss of toughness, in fact. The extreme case of the loss or tying up of energy occurs when large proportions of a metallic lattice are tied up in compound formation, the tough metal being reduced to the brittle compound. Upon ionisation in solid solution, the lattice energy which originally disappeared in molecular formation and in crystallisation is returned to the lattice, whereby gamma and beta solutions which contain ionised compounds are notoriously tough and the transition products are intermediate in toughness between these and the alloy which contains the crystalline compound phase, tending to be the less tough as ionised solubility is reduced progressively during the process of precipitation and crystallisation. Lattice energy appears to be tied up, to some small extent only, in the formation of unorientated grains and grain boundaries upon grain refinement by a pure form of treatment ; but, incidental to many a common form of treatment for grain refining, energy may be added to the lattice so that the observed effect may be an actual increase of toughness instead of the expected decrease. The effect of cold work on the simple lattice seems to be largely the tying up of lattice energy by the formation of the tiny slip-band crystallites around crystal blocks of preferred orientation ; whereby toughness is heavily sacrificed for strength until recrystallisation takes place. From this reasoning, and in fact from direct experimental work, it is evident that grain refinement in very advanced stages has the effect of tying up much lattice energy : only incidentals to the pure treatment for grain refining can have the effect of increasing toughness.

It will be remembered that Haigh's " strain energy " calculations provide criteria of metallic failure up to the elastic limit which most nearly agree with the results of actual experience or practice. This means nothing more or less than that " elastic toughness "—proof resilience—is the property of metals which is more effective in application to the practical case than either the elastic limit (maximum stress), or the strain at the elastic limit (maximum strain), or various other combinations which have been tried.

The serious attention of practising metallurgists is called to the above significant fact, coupled with the undeniable fact that, until very recently, true toughness in plasticity has never been measured properly at all. It would seem to be more than likely that correct measurements of the specific energies (toughnesses) of the metals and alloys would be only a beginning to considerations, on the above lines, of basic metallurgical treatment in a logical way. Before a metallurgist can advance his technique to procure alloys with mechanical properties superior to those now obtainable, he has the alternatives which are fairly clear by now. Either he discovers what are his aims by proceeding with any possible combination and permutation of treatment that occurs to him with the expectation that light will slowly dawn, or, as in the instance of fatigue investigation, he leaves treatment to follow the logical course of his investigation of aims. There is much hope on the horizon of the latter alternative ; toughness, which in the elastic form has proved the salvation of the engineer, can at last be measured with great ease, and can be taken as a measure of potential lattice energy. By means of such measurements, it may be found possible to isolate different component treatments in a treatment hitherto considered elementary, uncompounded. The usual technique may thereby undergo analysis for its own good, may become modified, amplified, and directly applicable to attain the new aims suggested by the investigation of the mechanical properties.

Copper-Alloy Resistance Materials

COPPER is so commonly used as a high-conductivity material that the full realisation of its importance as a basis of many resistance materials is seldom appreciated. The use of copper alloys as resistance materials is admirably discussed in a booklet of 44 pages, which gives details of the electrical and mechanical characteristics of such alloys, together with a brief outline of the manufacture of strip, wire and sheet, and their application in the construction of resistances and rheostats. Reference is made to practically all the reistance alloys which contain more than 25% of copper, although, naturally, there are many trade variations of any particular class which are not referred to specially. This is particularly the case with copper-nickel-zinc alloys.

The materials described are copper-nickel alloys ; low-temperature coefficient alloys containing manganese ; nickel silver ; copper-manganese alloys ; copper-manganese-nickel alloys ; copper-silicon alloys ; and other miscellaneous alloys containing copper. These materials, it should be noted, are not generally intended for use at temperatures above 350° C. This booklet is well illustrated, and is in keeping with the quality of the publications of the Copper Development Association. Copies will be supplied free of charge to readers, who give evidence of genuine interest, on application to the Copper Development Association, 9, Bilton Road, Rugby, Warwickshire.

The Nitriding Process

By E. Simister B.Sc., Ph.D.

(*Metallurgical Department, Kirkstall Forge, Ltd., Leeds.*)

The nitriding process has been extended considerably in recent years and many applications have been quoted from time to time ; to-day this form of treatment occupies a position of foremost importance as a surface-hardening method. The process is briefly described, modern types of nitriding steels and their heat-treatment are discussed, and some of the main features of nitriding equipment are described.

AT the beginning of the present century, chemists were investigating the action of nitrogen on heated iron. Later, Fry extended the researches and showed how an extremely hard skin could be produced on certain steels when they were exposed to nitrogen, under suitable conditions. To-day, as a result of this work, we have a process of steel treatment which occupies a position of foremost importance as a surface-hardening method.

In its main features the nitrogen hardening process is now fairly well known. A steel of special composition is heated at a temperature of some 500° C. in an atmosphere of ammonia, and by the absorption of nitrogen resulting from the dissociation of this gas, the surface of the steel becomes hard without the need for any further heat-treatment. The desired mechanical properties of the steel core are developed by prior heat-treatment and are fully retained during the low-temperature ammonia treatment.

Nitriding has advantages in certain directions over other methods of surface-hardening, mainly in the intense surface hardness and the consequently high degree of wear resistance which can be attained, and in the fact that the process, being carried out at a low temperature, under reducing conditions, is clean and scale-free, with distortion practically eliminated. It is generally adaptable to precision work and work of an intricate nature, which can be conveniently surface-hardened after finish machining. Importance attaches to the fact that nitriding can be applied to the high chromium nickel austenitic corrosion and heat-resisting steels.

The principle disadvantages from the manufacturing standpoint include the higher cost of the process compared with other methods of surface hardening and the very prolonged time of treatment required.

Nitrogen hardening covers a very wide field of service, but at the present time it finds some of its most important applications in aero-engine practice where it assists the ever exacting engine designer to meet the demand for engines of greater output and sustained reliability. Cylinder liners, crankshafts, airscrew shafts and valve stems may be cited as examples of parts to which the process has been successfully applied.

Steels for Nitriding

Although the majority of steels in use can absorb a certain amount of nitrogen under the appropriate conditions, only a few special types are capable of giving suitable combinations of case properties and core strength in the nitrided condition, to meet the requirements of constructional steels for engineering purposes. The surface of a plain carbon steel will absorb nitrogen, but the case so formed is soft and brittle and completely unsuitable for service, while the usual high tensile nickel-chrome-molybdenum steels develop core brittleness during the nitriding treatment.

(*Courtesy of the Bristol Aeroplane Co., Ltd.*)

Nitriding has played an important part in the development of the modern aero-engine. The illustration shows the "Bristol" Hercules sleeve-valve engine This is a 14-cylinder, double-row radial engine with an output of over 1,650 b.h.p.

The early work carried out on the nitrogen hardening process showed that it could only be successfully applied as a case-hardening method to those steels containing certain elements which had a distinct affinity for nitrogen and so giving rise to the formation of stable nitrides. Aluminium shows this property in a marked degree, while chromium, molybdenum and vanadium are also capable of forming suitably stable nitrides. The steels originally introduced as a result of Fry's researches on nitriding, contained aluminium in order to achieve the highest surface hardness with a certain amount of chromium to give depth hardening and a reasonable core strength, but in other steels developed subsequently more attention has been paid to securing high core

TABLE I.—SUMMARY OF NITRIDING STEELS.

Description.	Relevant Specification.	Composition, %.									Mechanical Properties.			
		C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	Al.	U.T.S. Tons/ Sq. In.	Y.P. Tons/ Sq. In. Min.	El., % Min.	Izod, Ft.-lb. Min.
1¼% Chromium-aluminium-molybdenum steel.	En. 41 D.T.D. 87A	0·18–0·45	0·10–0·45	0·65 max.	0·05 max.	0·35 max.	0·40 max.	1·40–1·80	0·10–0·25	0·90–1·30	35–45 45–55 55–65	24 32 42	24 20 17	45 40 35
3% Chromium-molybdenum steel.	En. 40 D.T.D. 306 D.T.D. 317A	0·15–0·35	0·10–0·35	0·65 max.	0·05 max.	0·05 max.	0·40 max.	2·50–3·50	0·30–0·70 V. 0·25 max.	— W. 1·0 max.	45 min. 50 „ 55 „ 60 „	34 38 44 48	22 20 18 17	45 40 40 35
2% Chromium-molybdenum steel.	D.T.D. 286A	0·32–0·48	0·50 max.	0·65 max.	0·05 max.	0·05 max.	0·40 max.	1·40–2·50	0·15–0·50 V. 0·25 max.	Opt. 0·60 max. W. 1·0 max.	55–65	45	18	35
1% Nickel-chromium-molybdenum Steel.	D.T.D. 228	0·25–0·35	0·35 max.	1·0 max.	0·05 max.	0·05 max.	1·00 max.	0·50–1·50	0·90–1·50 V. 0·25 max.	— W. 1·0 max.	55–65	45	18	35
High nickel-chromium-tungsten engine valve steel	En. 54 D.T.D. 49B	0·35–0·50	1·00–2·50	1·50 max.	0·05 max.	0·05 max.	10 min.	12·0–16·0	—	W. 2·0–4·0	Brinell 302 max.	—	—	15

strengths. The hardness of the case is attributed to the precipitation of the metallic nitrides in the crystal lattice of the iron.

Generally speaking, there may be said to be two main types of low alloy steels suitable for nitrogen hardening, these being the chromium-aluminium-molybdenum steels and the chromium-molybdenum steels. Both these types are summarised in Table I, which gives a résumé of current Ministry of Aircraft Production and British Standard Specifications covering steels approved for nitriding purposes. The 1¼% chromium-aluminium-molybdenum steel covered by D.T.D. 87A and En. 41 corresponds to the Nitralloy brand. This class of steel offers the highest response to the nitriding process, giving surface hardness values of about 1,100 V.P.N., and is used for those conditions in which maximum surface hardness is the primary consideration.

The chromium-molybdenum steels are covered by En. 40, D.T.D. 306, D.T.D. 317A, and D.T.D. 286A, and represent modern developments in the metallurgy of nitriding steels. It was found that the intense surface hardening effect introduced by aluminium was, for many purposes, undesirable, and for this reason the chromium-molybdenum steels have been introduced in which aluminium has been omitted. The increased chromium content compensates to a certain extent for the reduction in case hardness caused by the omission of the aluminium, and the toughness of the case is improved, so giving better resistance to shock conditions, with less danger of flaking.

The 3% chromium-molybdenum steel, with its excellent response to heat treatment, gives good core properties, even in the heavier sections. This is an important factor, as the core strength is not only responsible for the overall strength of a component, but also plays an important part in the durability of the hardened case, particularly as the nitrided cases are relatively thin. This class of chromium-molybdenum steel is finding increasing application for many high-duty components requiring a nitriding steel to the highest tensile ranges.

Specification D.T.D. 228 is listed as a nickel-chromium-molybdenum steel. To use a steel of this type successfully for nitriding purposes requires a careful balance of the composition in order to obtain a reasonable case-hardness and freedom from core-brittleness. In D.T.D. 228 the nickel content, which is limited to a maximum of 1%, assists in obtaining the required core strength, whilst the molybdenum content, which has been stepped up to about 1% or more, counteracts any tendency to embrittlement and improves the toughness and penetration of the case.

The nickel-chromium-tungsten steel corresponding to En. 54 and D.T.D. 49B, is a high-duty valve steel, and is given as an example of the type of austenitic steel to which the nitrogen hardening process may be extended for special purposes, as, for example, the superficial hardening of the stems of aero-engine valves.

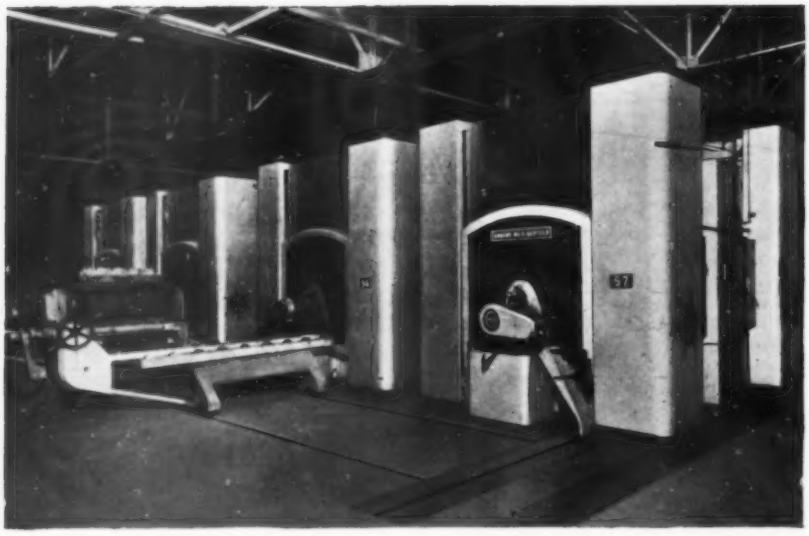
It will be seen that some of the specifications cover a wide range of composition as regards carbon content and the particular analysis to be selected for any purpose would depend upon the tensile condition required. For the highest tensile condition, the higher carbon contents would be selected. In this connection, it may be noted that the skin hardness after nitriding is in no way affected by the hardness or tensile strength of the core. With the standard nitriding treatments, the surface hardness will be solely dependent upon the alloy content of the steel.

Although the aluminium or chromium contents are mainly responsible for giving surface hardness, the presence of molybdenum is essential in a nitriding steel to overcome temper-brittleness, which would be a real danger in view of the prolonged low-temperature treatment. Molybdenum also improves the case properties, and by its influence on the depth-hardening characteristics, improves the heat-treatment response of the material.

The silicon and manganese contents of the various steels are only there to fulfil their usual functions, and are not intended to play any major part in the nitriding reactions.

Heat-treatment of Nitriding Steels

Suitable thermal treatment temperatures for the various nitriding steels are indicated in Table II. Care in temperature control should begin at the forging



(Courtesy of G.W.B. Electric Furnaces, Ltd.)

Fig. 1.—Battery of double-ended electric nitriding furnaces for crankshafts.

furnace as the chrome-molybdenum type of steel may be found rather susceptible to overheating. In practice, the highest permissible temperature will depend to a certain extent upon actual furnace conditions, but the figure of 1,150° C. is regarded as a safe maximum to which the steel may be heated in the furnace. The steels should be slowly cooled after forging.

Owing to their alloy content, nitriding steels have distinct air-hardening properties, and, after hot-working, some annealing treatment is recommended to facilitate rough machining. Forgings in 3% chrome-molybdenum steel will frequently require a prolonged soak at 700° C. to bring them down to a Brinell figure of about 235 suitable for rough machining. In some cases a double treatment may be specified after forging, consisting of air-cooling from 900°–920° C., to homogeneise and refine the as-forged structure, followed by several hours' treatment at 680°–700° C. for softening, with air or furnace cooling as desired.

TABLE II.
HEAT-TREATMENT OF NITRIDING STEELS.

Steel.	Heat-treatment Temperatures.
1½% Chromium-aluminium-molybdenum En. 41. D.T.D. 87A	Forging: Max. 1,150° C. Finish at 900° C. Annealing: Soak at 700° C. Hardening: 890°–910° C. Oil quench. Tempering: 600° C. min. Air cool. Stabilising: 520° C. min. Air cool. Nitriding: 500° C.
3% Chromium-molybdenum En. 40. D.T.D. 306. D.T.D. 317A	Forging: Max. 1,150° C. Finish at 900° C Annealing: Soak at 700° C. Hardening: 890°–910° C. Oil quench. Tempering: 570° C. min. Air cool. Stabilising: 520° C. min. Air cool. Nitriding: 480°–500° C.
2% Chromium-molybdenum D.T.D. 286A	Forging: Max. 1,150° C. Finish at 900° C. Annealing: Soak at 680°–700° C. Hardening: 900° C. Oil quench. Tempering: 600° C. min. Air cool. Stabilising: 500°–550° C. Air cool. Nitriding: 500° C.
1% Nickel-chromium-molybdenum D.T.D. 228	Forging: Max. 1,150° C. Finish at 900° C. Annealing: Soak at 650°–680° C. Hardening: 875° C. Oil quench. Tempering: 600° C. min. Air cool. Stabilising: 500°–550° C. Air cool. Nitriding: 475°–500° C.

The required mechanical properties of the core material are developed by hardening and tempering before the nitriding treatment. It is generally stated that for the best properties in the nitrided case the core must possess a uniformly sorbitic structure, and so efficient heat-treatment becomes essential both for the strength of the core and for the durability of the case.

All the nitriding steels are oil-hardening types, and the hardening temperatures are somewhat higher than is usual for many alloy steels owing to the sluggishness with which solution takes place in this class of material. As a precaution against hardening cracks, the parts may be removed from the oil-bath while still warm. There should be no delay between hardening and tempering, and the tempering must be carried out as fully as possible to ensure the complete removal of quenching stresses. To further minimise internal stressing, tempering is followed by air-cooling.

Stabilising

To avoid distortion taking place during the prolonged ammonia treatment, any residual stresses arising from heat-treatment and subsequent machining operations, are removed by a low-temperature stabilising treatment. This stabilising treatment is an important part of the heat-treatment procedure. It may not be necessary for simple items, such as short cylindrical pins, but for other components, such as crankshafts, it becomes essential.

In many cases the stabilising treatment would be carried out after machining to approximately $\frac{1}{32}$in. of the finished size, but for special work where the parts are long and intricate, or have considerable differences in section, or where heavy machining is to be performed, it is desirable to introduce an additional stress relief by stabilising after rough machining and again after semi-finish machining.

The stabilising temperatures are in the range 500°–550° C., being somewhat lower than the tempering temperature, so as not to affect the previous heat-treatment, but higher than the nitriding temperature. The parts are held at temperature for about 5 hours and slowly cooled. To avoid scale-formation, this treatment can be carried out in controlled atmosphere furnaces.

Ammonia Treatment

Before the components are exposed to the ammonia atmosphere the surfaces to be left soft are suitably protected from the nitriding gas, for which purpose tin-plating is generally recommended. If desired, the parts can be tinned all over and then finish machined on the surfaces to be hardened. Screw-threads should not be overlooked in the tinning operations, as otherwise they are likely to be embrittled by the double-sided penetration of nitrogen. It is good practice, if possible, to avoid

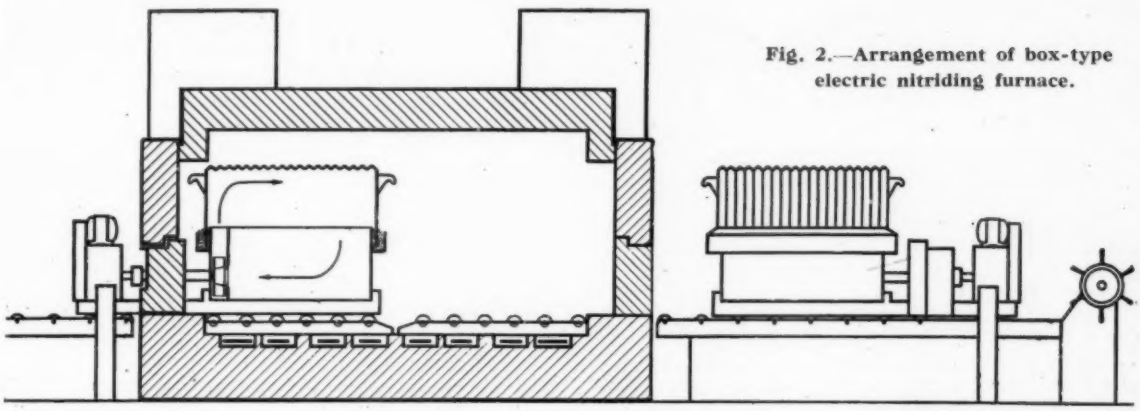


Fig. 2.—Arrangement of box-type electric nitriding furnace.

nitriding any sharp corners, as the extra penetration which takes place produces a relatively deep case on the corners which, lacking the full support of the core, are very prone to chipping. A sufficient radius should be provided to overcome this weakness.

The surfaces exposed for nitriding must be free from scale or decarburisation, and the parts should be solvent cleaned or degreased before nitriding to ensure chemical cleanliness for efficient absorption of the nitrogen.

For the nitriding operation, the parts are placed in a container usually of heat-resisting high nickel-chromium alloy through which the nitriding gas can circulate and which is arranged for external heating in a suitable furnace. No packing material is used in the box, and the work must be so placed as to permit free and uniform circulation of the ammonia with adequate support to prevent sagging during treatment. The cover of the box is made gas-tight to avoid leakage of ammonia and ingress of air during heating and cooling.

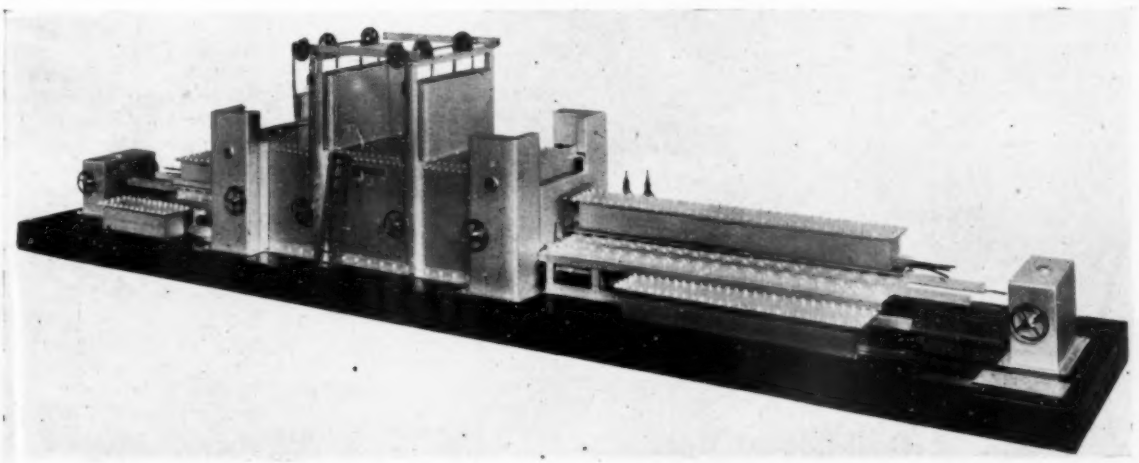
The container is provided with inlet and outlet tubes for the circulation of the ammonia gas which is supplied at a controlled rate from cylinders of high-purity anhydrous ammonia. At the beginning of a run, ammonia is circulated until all the air has been displaced before heating is commenced and the flow of ammonia is maintained during the nitriding treatment at a slight positive pressure. The duration of the ammonia treatment depends, of course, upon the depth of case required, and in practice varies between 10 hours and 100 hours. At the conclusion of the prescribed period, the container and its contents are allowed to cool down, but the gas flow is continued until the components have cooled to about 150°–100° C.

Pyrometers are installed both in the box and in the furnace, and during treatment the temperature is maintained within 5° C. of that specified for the steel.

The progress of the nitriding reactions is dependent upon the dissociation of the ammonia taking place at the surface of the steel, according to the reaction $NH_3 \rightarrow N + 3H$. Only nitrogen which is in the atomic form is active in nitriding, and a portion is absorbed in the surface of the steel and diffuses inward, while the remainder assumes the molecular state so becoming inactive. During the treatment there must be a sufficient flow of ammonia to ensure an adequate supply of atomic nitrogen at the surface of the work.

The proportion of ammonia dissociated varies in practice between about 20% and 60%, 30% being a customary value. The higher dissociation values reduce the consumption of ammonia, but there is danger of

Fig. 3.—100 k.w. nitriding furnace specially designed for varying lengths of nitriding boxes.



(Courtesy of G.W.B. Electric Furnaces, Ltd.

producing a case of inferior properties if the dissociation becomes too high. Inefficient circulation of ammonia through the charge may result in pockets of stagnant gas, in which the dissociation becomes dangerously high. To overcome this possibility, particularly when high dissociations are being worked, precautions have to be taken to ensure thorough circulation of the gas, and if necessary a fan should be installed to give uniform conditions in the container.

The optimum dissociation value for any particular job depends upon the equipment and the charge, but this value should be determined and maintained by checking at regular intervals.

The actual ammonia consumption will vary between different installations, but in furnaces of average size, 1 lb. of anhydrous ammonia will nitride 75–100 sq. ft. of surface per hour.

Furnace Equipment

For nitriding purposes it is essential to have accurate temperature control with close uniformity of heat-distribution over long periods, and furnace equipment is now specially designed to meet these requirements.

Fig. 1 shows a battery of nitriding furnaces installed for treating aero-engine crankshafts, and a sectional view of one of these furnaces is shown in Fig. 2. They are of the double-ended type, with idler roller hearths accommodating two charge containers which are handled by a charging machine at either end of the furnace. For uniformity of heating, each furnace is split into two heating zones having a total rating of 80 kw. The total output is 40 crankshafts per cycle. In the installation shown, a special design of container is employed and fitted with a fan to maintain efficient circulation of the nitriding gas through the charge.

On the conclusion of a nitriding period the containers are cooled to a suitable temperature in the furnace and then withdrawn by the charging machines for air cooling before being emptied. The lids of the containers are powder sealed.

The equipment is provided for pyrometric control over both the charge and furnace temperatures, and the ammonia dissociation panels mounted on the side of the furnace enable control over the nitriding conditions.

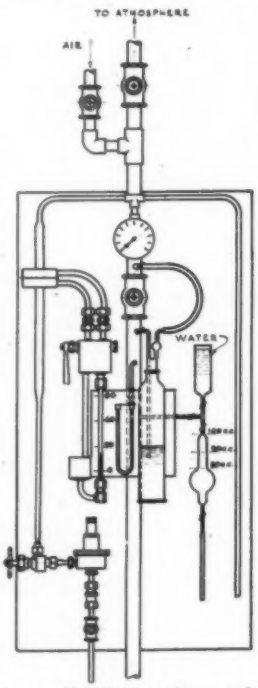
Fig. 3 represents a nitriding furnace specially designed for treating components in a particularly long box. The furnace chamber is 21 ft. long, but is sub-divided into three compartments so that shorter boxes may be accommodated without affecting the furnace efficiency.

Furnaces operating on the cyclone or forced convection principle have been adapted to nitriding purposes, particularly in American practice. In using this system with electrical heating a large volume of air is blown round in a closed circuit between the heating coils and the separately placed nitriding chamber. A constant volume of air is in continual circulation, the circulating fan being arranged to handle the cooler air which is drawn away from the nitriding chamber.

The cyclone principle can also be used with gas heating, in which case the combustion gases from a separate combustion chamber pass round the nitriding chamber by forced circulation. A large volume of hot gas is kept in circulation at a high velocity and into this stream the hot products of combustion are mixed, the excess volume passing out through a flue after having imparted its heat to the nitriding container. Thermo-couples are installed to measure the temperature of the circulating gases, the furnace temperature being controlled by regulating the volume of combustion gases entering into circulation.

A recently described American installation of this type has been specially designed for nitriding tank-track pins. The full furnace charge is 10,000 track pins, measuring $9\frac{1}{2}$ in. long $\times$ $\frac{3}{4}$ in. diameter, and of 12,000 lb. total weight. A case depth of 0·025 in. to 0·030 in. is obtained with an actual nitriding time of 112 hours.

Semi-continuous furnaces are in fairly extensive use, one of the best known being the bell type or " top-hat " furnace. In these installations the work is contained in a sealed chamber through which the ammonia can be passed. The heating unit, however, is portable, and at the end of one nitriding cycle can be lifted off and transferred into position over another nitriding chamber which has been charged ready.



Courtesy of G.W.B. Electric Furnaces, Ltd.

Fig. 4.—Arrangement of ammonia control panel.

It is possible to utilise the spent nitriding gases coming from one charge to purge a second retort free from air before the commencement of the heating operation. A fan is frequently fitted in the nitriding chamber to improve the gas circulation through the work.

Furnaces of this type may be heated by electrical resistance elements, or gas-fired radiant tubes. A system of forced convection has also been used in which hot gases from a separate combustion chamber are circulated under the bell and round the container. The heating unit is usually arranged to be lifted off, but there are other arrangements operating on the same principle, in which the furnace unit is mounted on wheels for transference from one nitriding station to another.

Where the production requirements justify its use, certain advantages are attributed to the bell-type of furnace as the furnace unit can be in practically continuous operation serving two nitriding stations. On the other hand, the fixed or box type furnace permits of more substantial construction and its efficiency is high.

Measuring Instruments

The need for control of the nitriding gas composition has been mentioned, and probably the best known method of measuring the dissociation is by means of an absorption burette such as is shown on the control panel illustrated in Fig. 4. A sample of the gas leaving the nitriding container is collected in the burette, and water is then admitted in which the undissociated ammonia dissolves. The dissociation is measured by the volume of the residual gas in the burette. A furnace atmosphere analyser has also been introduced which functions by

measuring the gas density, and enables a continuous record of the dissociation to be obtained throughout the cycle.

For indicating the rate of flow of ammonia into the nitriding chamber the orifice flow-meter is suitable and can be arranged to give a direct reading of the gas-flow. The Rotameter may also be employed for this purpose. In this instrument the gas under measurement passes up a vertical glass tube made with a slight taper bore. In the tube is a small cylindrical shaped float, which, in

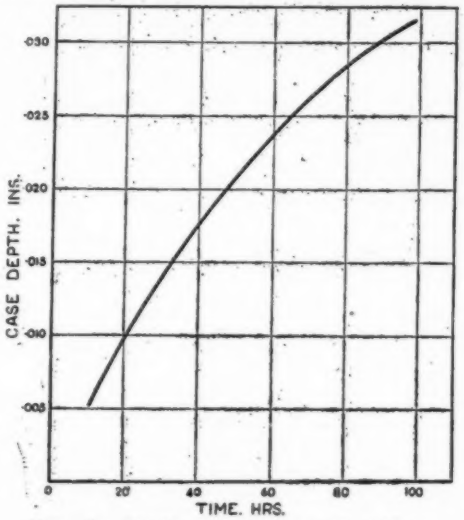


Fig. 5.—Depth of case produced on chromium - aluminium - molybdenum steel nitrided at 500° C.

operation, is supported by the gas stream at a position depending upon the velocity head. The gas flow is thus indicated by the height of the float in the tube.

The Nitrided Case

As previously indicated, the hardness of the nitrided case produced under the correct conditions is dependent only upon the alloy content of the steel. The greatest hardness is attainable with the aluminium-bearing steels, and D.T.D. 87A is capable of giving 1,100 V.P.N. The 3% chrome-molybdenum range will give 800–850 V.P.N. and D.T.D. 286A about 750 V.P.N., while the nickel chromium-molybdenum steel D.T.D. 228 will give about 600 V.P.N. This decrease in the case-hardness of the various steels is accompanied by a corresponding increase in the toughness of the skin and a reduced tendency to spalling or flaking. The prescribed nitriding temperatures should be adhered to within the limits stated, as the use of an excessive temperature produces a case of lower maximum hardness and inferior properties. The case depth-time relationship for chrome-aluminium-molybdenum steel nitrided at 500° C. is represented in Fig. 5.

It is well known that the maximum hardness of the nitrided skin is not developed at the extreme surface, but at a point 1–2 thousandths of an inch below, the hardness gradient through the case as nitrided being generally as indicated in Fig. 6. The surface as nitrided is reported to have good corrosion resistance, but as its mechanical properties are not completely satisfactory, it is usually removed by light grinding to give a case with maximum resistance to wear and service stresses.

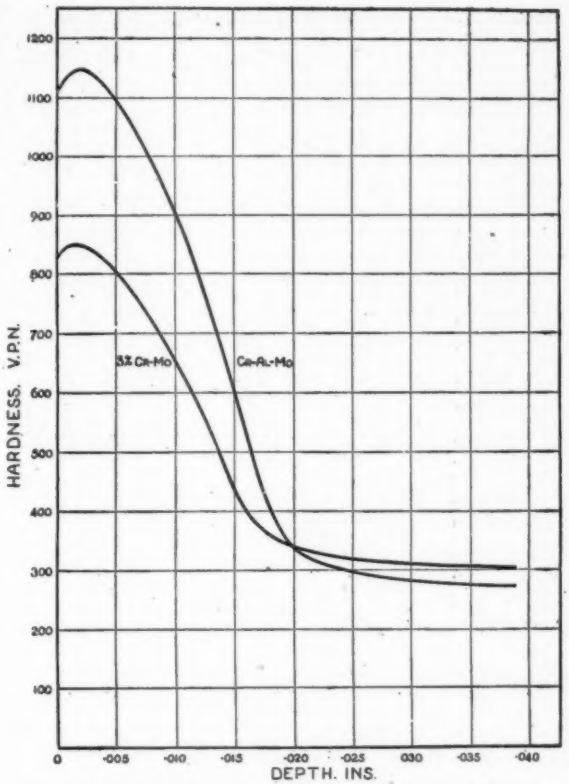


Fig. 6.—Hardness gradients through sections of nitrided cases produced on chromium-aluminium-molybdenum and 3% chromium-molybdenum steels.

The nitrided case has the useful property of retaining its hardness at higher temperatures. A carburised case softens fairly rapidly about 250° C., whereas the hardness of a nitrided case only begins to fall off at about 450° C.

During the nitriding treatment there is a slight increase in size of the order of 0·002 in., the actual extent depending upon the time of exposure to the ammonia. This growth is substantially constant, and once it has been determined for a given set of conditions, the necessary allowance can be made. Surface decarburisation is reported as bringing about increased growth on nitriding, in addition to which the toughness of the case is impaired and consequently adequate machining allowance has to be provided to ensure the removal of all decarburisation.

Nitrogen-hardening has a most valuable influence in increasing resistance to fatigue and in reducing the notch sensitivity of surfaces so treated. These effects are attributed to compressive stresses which are developed in the nitrided case, and this aspect has recently been discussed in some detail by Bardgett.*

It is not proposed to deal at length with the various applications of nitrogen-hardening. The process has been extended considerably during the past 10 years, and many applications have been quoted from time to time, including numerous types of spindles, pins, links, bushes, guides and plungers, etc., where the wear resistance of the nitrided case has been responsible for a greatly increased service life, sometimes under difficult

* "Metal Treatment." Summer, 1943.

conditions. In common with other methods of surface hardening, however, nitriding has its particular shortcomings, and these have to be recognised in considering any specific application of the process.

For some purposes the nitrided case is at a disadvantage owing to its reduced resistance to shock conditions, or pressure loading. Under ordinary rubbing action, the nitrided skin functions extremely well, but it does not so successfully withstand impact or pounding actions, or loading under high local pressure, such, for example, as may be encountered on gear teeth.

The main reasons against the wider adoption of the process include the need for special equipment and the length of time required for the production of substantial case depths. Nevertheless, it is certain that the process will find increasing application in high-duty service, particularly for those purposes where costs of material and procedure are secondary considerations.

Some Recent Heat-Treatment Plant Installations

For Vital and Urgent Production Programmes

The urgent demand for heat-treatment equipment during recent years has presented many problems, which, under normal conditions, would have involved experimental and development work to reach solutions. To meet the emergency, production engineers, metallurgists and heat-treatment plant designers have co-operated, and although the marked increase in size of equipment necessary has been largely accomplished by improvisation and adaptation, much development is evident, as this brief review, giving interesting examples, will show.

THE successful heat-treatment of ferrous and non-ferrous components depends upon so many factors that the design of suitable heat-treatment plant is very complex. In whatever form heat is applied to a furnace, the manner in which it reaches the surface of the component undergoing treatment is of great importance. This is one of the primary factors to which design and the method of handling a furnace is directed. Closely associated are those factors which concern time and rate of heating and cooling. Ideal conditions can more nearly be approached when a furnace is to be designed for the heat-treatment of mass-produced components exactly similar in size and design and of uniform section. Even so, the heating or cooling medium must be applied uniformly to the whole surface of each individual component, at the same temperature, at the same rate, for the same time, and in the same atmosphere, to produce uniformly heat-treated products. Usually a compromise must be made to obtain the best results variable conditions will permit.

The demand for heat-treatment furnace equipment, due to the enormous production programmes of the past few years, has necessitated a greater degree of compromise in design. In many instances the urgent character of the demand prevented the progressively planned experimental and development work which would normally precede the design and installation of large-scale manufacturing plant. The solution of many heat-treatment problems has been arrived at by improvisation and adaptation rather than by fundamental discovery and invention. Processes have been applied to analogous jobs on a scale which would not have been regarded as reasonable in more normal times without experience with smaller installations. However, very considerable progress had been made immediately before the war, not only in the design of heat-treatment equipment, but in heat-treatment technique, and the experience then gained has been an invaluable asset in dealing with the new problems encountered in the production of the implements of war.

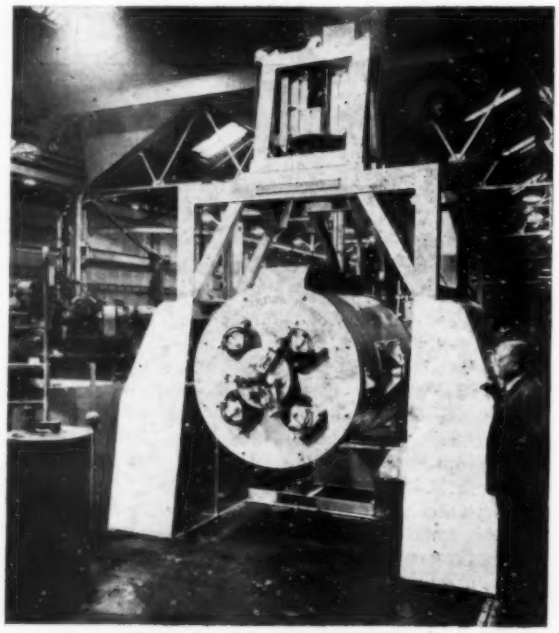


Fig. 1.—Rotating retort type furnace suitable for gas carburising small components in bulk.

Despite the urgency associated with new furnace installations, there have been many developments in both heat-treatment technique and in equipment, and while much of the information relating to these cannot yet be given, due to war-time restrictions, from the few examples available, and briefly described in this article,

(*Courtesy of Laystall Eng. Co. Ltd.*)

Fig. 2.—Complete plant for carburising in "Rapideep" or cyanide baths.

it can be reasonably assumed that the heat-treatment furnace manufacturers of this country are maintaining an advanced position among the manufacturers of the world.

Carburising

Pack carburising with solid compound is a time-honoured process which has sometimes been partially mechanised by using continuous furnaces in which the boxes are conveyed through the furnaces by means of mechanical pushers. This method is only applicable to the mass production of components all requiring approximately the same carburising cycle. It has been applied to the large-scale production of gears and similar components.

In America, gas carburising has been in use for some years, although much of the early fundamental work on this subject was carried out in this country by Bramley and his co-workers. In the States, commercial development of the process was favoured by the occurrence in many areas of large resources of natural hydrocarbon gas, from which a suitable gas carburising medium could be readily prepared. In this country, the absence of such resources made the development of gas carburising on the industrial scale a more difficult problem, but this has now been resolved, and gas carburising processes are available which compete very favourably with pack carburising on a basis of direct operating cost, and in addition give all the advantages peculiar to this method of case hardening.

Some of these advantages of gas carburising are :—

(i) A shorter overall cycle for a given case depth, due to shorter heating-up time. The reduction may be as great as 50% on case depths of the order of 0·020 in.

(ii) Saving in fuel consumption, due to shorter cycle and absence of dead-weight of boxes and compound.

(iii) Elimination of box and compound handling, with resultant greater cleanliness and reduction of labour needed.

(iv) Uniformity of case depth throughout the charge, within very narrow limits.

(v) Complete control of depth and type of case.

(vi) The process can be readily adapted to direct quenching from the carburising furnace, where this is desirable.

Several installations are in successful use, including batch furnaces of both the stationary and rotating retort type, and have amply proved the above advantages in practice. Fig. 1 shows a rotating retort type furnace by Birmingham Electric Furnaces, Ltd., suitable for the gas carburising of small components in bulk. The furnace is arranged to tilt for direct quenching, and is completely mechanised, the bung being mechanically withdrawn for charging from a hopper.

Fig. 3.—A vertical cylindrical nitriding installation for aircraft engine cylinder liners.

Another method of gas carburising, by which any depth of case in the carburising range is secured uniformly, is the Homo method of short-path forced convection circulation. By this method a constant, accurate injecting device feeds the furnace with "Homo-carb" fluid, a carbon source especially purified and practically uniform. Inside the furnace it becomes a gas which a high-pressure fan forces, at full carburising temperature, to every surface of every piece in the load. Both carbon distribution and temperature are under close control, and the carburised case develops at a rate which is both uniform and rapid.

An interesting plant for carburising in "Rapideep" or cyanide is shown in Fig. 2. The furnaces are gas-heated and have pots of internal dimensions 24 in. diameter by 21 in. deep, and are fitted with preheaters for drying and preliminary heating of charges. Each

Fig. 4.—The Homo nitriding furnace.

furnace is provided with an individual fan and gas-pressure governors for accurate control of combustion, and has four burners, each operated by a single lever for simplicity of control. The charge accommodated by one of these furnaces may be as high as 3 cwt. to 4 cwt., and overhead lifting gear is necessary above the loading station, preheater furnaces and quenching tanks.

The total charge time for a given case depth in the "Rapideep" bath is claimed to be considerably shorter than in the solid compound, and the output of the furnace is high in relation to first cost and floor space occupied. For shallower cases the 50% sodium cyanide bath is preferable. All these baths, which are to the design of Cassell Cyanide Co., Ltd., have the advantage of accurate temperature control, freedom from scale, clean finish and high rate of production.

Nitriding

That experience gained on comparatively small furnaces has been successfully applied to much larger ones is admirably shown in Fig. 3, which illustrates an installation by General Electric Co., Ltd., for nitriding the cylinder liners of a well-known aircraft engine. It consists of three vertical cylindrical furnaces with automatic temperature control gear, gas control cubicles, and sufficient containers to enable the furnaces to work continuously. The parts which are nitrided in these furnaces are of such delicate design and proportions that the greatest care must be taken to support them in the furnace in order to reduce to a minimum the possibility of distortion. This is achieved by loading the components on special heat-resisting alloy castings, which are assembled and lowered into the nitriding chamber.

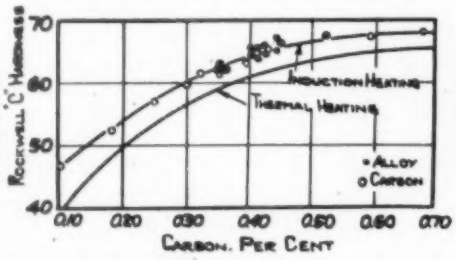


Fig. 5.—Results of tests showing increased hardness obtained by means of induction heating.

The Homo nitriding furnace is another example of applying this method of producing a hard case. Built of special materials by the Integra Co., Ltd., it has an oil-sealed lid and devices for regulating an ammonia gas supply. Work is loaded into a basket or on trays which are lowered into the furnace chamber. With the lid closed, the flow of ammonia gas is started and the fan turned on. As soon as the gas mixture is suitable, electric heating coils, which encircle the chamber, supply a steady flow of heat. As the control point is approached, the rate of heating is reduced automatically, so that temperature climbs smoothly to soak, where it is held evenly as long as desired. At the end of a run, the furnace atmosphere circulates through a water-jacketed manifold and cools rapidly. In production-type furnaces, the fan reverses direction automatically at frequent intervals. This type of furnace is shown in Fig. 4.

Induction Heating

Inductive heating, a more recent method of applying heat for the hardening, tempering, normalising and annealing of metals, is only on the threshold of its possible application and the last few years have appreciably accelerated its development.

It has a number of unique advantages of which the most obvious is its ability to develop heat where it is most required. It frequently happens in practice that only part of the article requires heat-treatment. By other methods it is usually necessary to heat the whole article. At its best this is a waste of power and at the worst has a serious effect on the physical properties which have been obtained by previous treatment. For instance, a gearwheel which has been made in a direct hardening steel, that is one with a medium, or higher, carbon content can be surface-hardened on the faces of the teeth without interfering with the physical properties of the hardened and tempered core of the tooth and, of course, of the wheel.

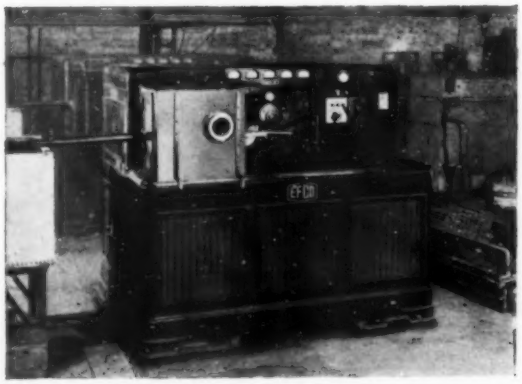


Fig. 6.—A typical Tocco Junior induction heating installation for hardening pins.

Another important point which is at first sight not so obvious, is brought out by the mechanism of heating for hardening. As is well known, hardening depends on retaining iron carbide in solution in α-iron and the greater the amount in solution the higher is the hardness. Heating inductively gives a very rapid rate of solution of carbide in austenite. A reasonable explanation of this is that owing to its higher specific resistance relative

to ferrite, the iron carbide reaches a higher temperature which promotes solution. This would explain the superhardness which is obtained by inductive heating. By the usual method complete carbide solution and, more important still, complete diffusion in austenite, is not obtained, but induction heating accomplishes this and results in a very fine nodular martensite which contrasts with the usual acicular structure. The curves shown in Fig. 5 are based on results of tests obtained by the Osborne Co., and Burns, Moore and Archer, and indicate the increased hardness obtainable.

By this method, heat is developed only where required. The order of time varies from 1–100 secs., 5–15 secs. being a fair average—and such rapid heating eliminates grain-growth problems. When controlled atmospheres are an advantage they can be readily applied with a substantial saving in cost as compared with normal furnace practice, as purging of large furnace chambers is avoided. The outstanding advantages of induction heating include :—

(1) It enables parts which require localised heat-treatment to be handled satisfactorily and economically.

(2) It minimises distortion and permits of much smaller grinding allowances sometimes eliminating the need for any.

(3) Where a product would not benefit from the above advantages the improved physical properties obtainable and the rapid heating by induction should be considered.

(4) It lends itself particularly to continuous treatment and is on mass-production lines. The treatment cycle is made automatic and fool-proof, and reproduces constant results indefinitely.

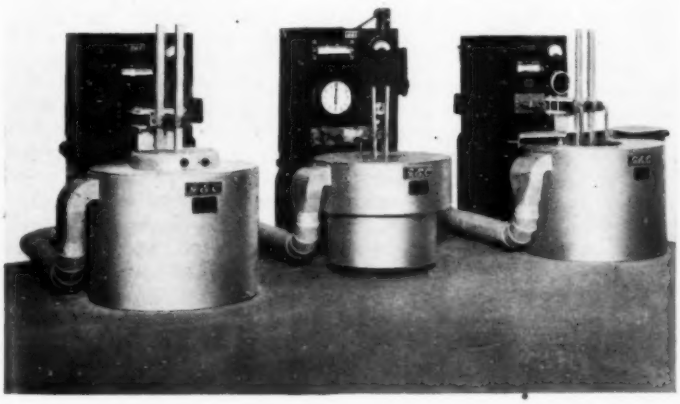


Fig. 7.—Set of three electrode type salt-bath furnaces for high-speed steel tool-hardening.

(5) It eliminates or minimises surface decarburisation.

The possible applications of induction heating are too numerous to describe here, but brief reference can be usefully made to its use for the surface hardening of pins and journals of crankshafts, camshafts, gears of all types, and track pins. A typical installation, by courtesy of the Electric Furnace Co., Ltd., is shown in Fig. 6.

The majority of induction heating processes require a frequency higher than that of the normal electric supply, and this will depend on the size and nature of the article to be treated. However, it can be said in general that the shallower the depth of heating, the higher the frequency. In practice, the most commonly used frequencies range from 2,000–10,000 cycles per second, although much higher frequencies are being used for special purposes.

Fig. 8.—An installation for the heat-treatment of light alloy airscrew blades, comprising two vertical forced air circulation furnaces.

The problem of generating H.F. power resolves itself, in practice, into converting the normal mains frequency (50 cycles in Great Britain) to high frequency. The type of converter used depends on the frequency required and three types in common use are as follows :—

(1) Motor generator sets for frequencies up to 10,000 cycles.

(2) Spark gap-equipments up to 300,000 cycles.

(3) Electronic oscillators up to about 5,000,000 cycles for induction heating and much higher frequencies when required for other work.

No induction heating application has yet been found which is too large for motor generator capacity. The size of spark gap sets is, however, limited, and their use does not appear to be practical in large units. With valve sets the upper limit of size is dictated mainly by economic considerations. There would be no special difficulty in normal times in the manufacture of a 500–1,000 kw. equipment for induction heating work, should such a size be justified. The highest efficiency of all these converters is obtained from motor generator sets. Typical figures range from 75 to 85%, depending on the power and frequency of the machine. Valve-operated equipments can be used at efficiencies between 65 and 75%, but the higher efficiencies, with valve equipments, tend to promote short valve life and lower reliability. For highest reliability it is believed that an efficiency of 50 to 60% is preferable. The lowest efficiencies are recorded with spark-gap equipments where figures of 40 to 55% are usual, more or less independent of frequency and power.

Fig. 9.—A gas-fired air circulation pit type furnace for the solution treatment of aluminium alloy components.

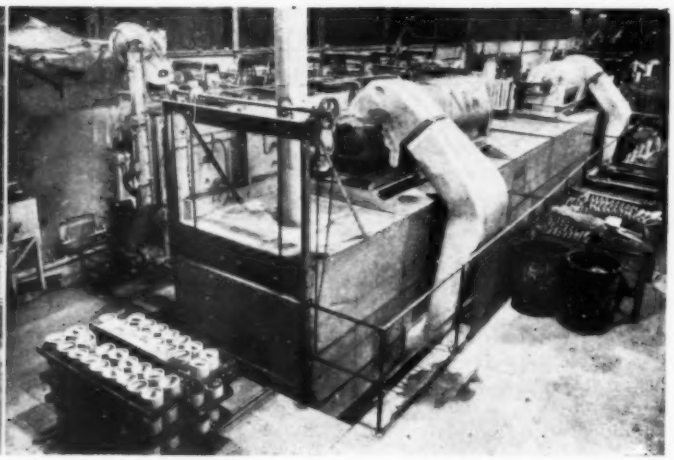


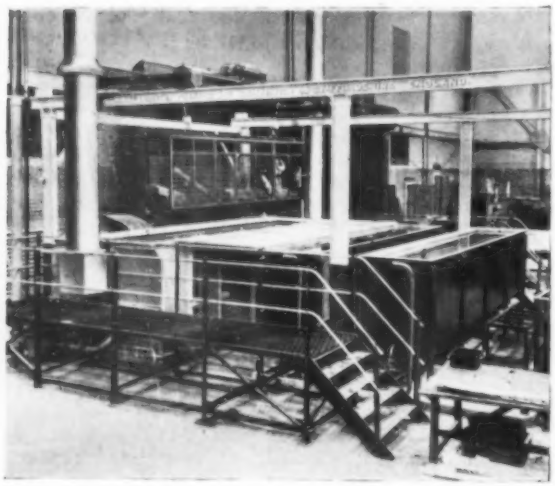
Fig. 11.—A gas-fired air circulation furnace for age-hardening aluminium alloy components.

Hardening Equipment

In view of the modifications in the composition of high-speed steels, attention has been directed to their successful hardening. For this purpose salt-baths have become increasingly popular for the molybdenum high-speed steel. Experience has shown that the results obtained with the salt-bath process are comparable with those of the older tungsten steels. Imperial Chemical Industries, Ltd., have developed a salt known as "Carboneutral" for use in these baths. The full equipment for salt-bath treatment include a suitable pre-heating, quenching and secondary hardening furnaces.

While various methods of heating are applied, there has been a considerable increase in the use of the electrode type salt-baths. Two main types are employed suitable for high and low temperatures respectively. The high-temperature furnaces, used chiefly for hardening high-speed steel tools, working at temperatures of 1,200° to 1,400° C., and the low-temperature furnaces, for preheating high-speed steel tools before they are immersed in the high-temperature furnace, are generally suitable for temperatures of 500° to 1,000° C. Their chief virtue lies in the speed with which tools can be heated and the absence of scaling which is liable to destroy fine cutting edges. An installation of three of these furnaces, by General Electric Co., Ltd., is shown in Fig. 7. The furnace on the left is for preheating the tools, the centre one is the high-temperature hardening furnace, and that on the right is used for hot-quenching. In some instances the preheating is done in a muffle furnace, and, frequently, the third furnace is dispensed with and the tools are quenched in oil.

Fig. 10.—Salt-bath plant for normalising light alloy airframe components.



A furnace specially designed for the accurate and scientific hardening of intricate components or tools is the "Vapocarb Hump" hardening furnace of the Integra Co., Ltd. This furnace embraces three vital factors—viz., control over the rate of heating which eliminates distortion, splitting and cracking; control over the quenching point which enables very accurate results to be obtained and also duplication whenever required; and the atmosphere used gives control over the surface during hardening and enables components or tools to be treated free from blemishes such as scaling, decarburisation, and soft spots.

Many pusher types of hardening furnace are in use, and a recent design of this type is a continuous furnace by Hind-Griffiths, an interesting feature of which is that a small portion of the load is quenched at regular intervals, necessitating the use of only small quenching tanks and oil-cooling equipment. Installations of this design are being applied to the hardening of steel forgings for aircraft components.

Treatment of Light Alloys

With the phenomenal progress in the production of aircraft, it is not surprising that heavy demands have been made for equipment to cope with the aluminium alloy parts. Again the need for larger types of plant has predominated, and among recent developments of this character is the installation by Wild-Barfield

Electric Furnaces, Ltd., shown in Fig. 8. It comprises two vertical forced air circulation furnaces for the heat-treatment of light alloy airscrew blades. The furnaces accommodate charge carriers with useful capacity, 84 in. diameter and 96 in. deep, the top of such a carrier, already loaded, being visible in the foreground.

Whilst this equipment is considerably larger than this firm's standard vertical forced air circulation plant and incorporates many special features, the same operating principles are employed in so far as the air is circulated continuously by the centrifugal fan through the annular space formed by the insulation and inner drum in which the heating elements are mounted, and down through the charge. In view of the size of the equipment, the fan is mounted in a specially constructed door which is carried on a hand-operated bogie, and lifted through the medium of a number of jacks around its periphery, operated by a single handwheel. To take the major part of the door weight, leaf springs are incorporated.

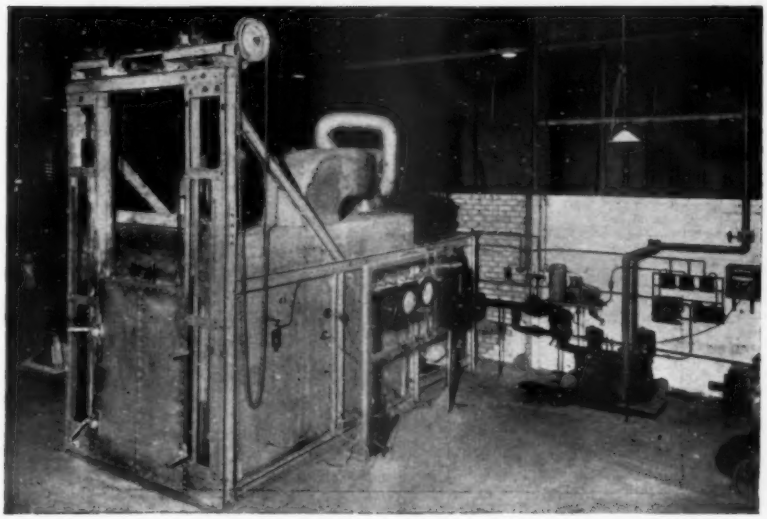


Fig. 12.—An oven used for the heat-treatment of magnesium alloy castings.

Each installation is identical, comprising two such furnaces with a large quench tank, heated either by immersion heaters or a steam coil, and full control gear. The loading of each furnace is 150 kw.; with input reduction for soaking purposes. The control gear comprises a non-indicating controller with separate 2-point drum type recorder for each furnace. The quench tank has its own dial thermograph, and automatic temperature controller when heated by immersion heaters.

The complete switchgear cubicle with the various isolators, input reduction switch and oil circuit breaker can be seen to the rear of the quench tank. A special 3-ton, 2-motor electrically operated crab also forms part of the equipment, to give rapid transference of the charge from the furnace to the quenching tank.

A gas-fired air circulation pit furnace for the solution treatment of light alloys is shown in Fig. 9. Designed and constructed by Controlled Heat and Air, Ltd., it accommodates a basket of 7 ft. 6 in. high and 4 ft. diameter, and comprises an inner and outer casing, the 12 in. space between them being filled with Moler insulating powder. The combustion chamber is located external to the working space, and is fired by multijet luminous burner. The steelwork forming the combustion chamber is extended to carry a centrifugal fan which is located immediately above the chamber.

The distribution system inside the furnace casing comprises two supply headers located adjacent to the combustion chamber, together with a recirculating header. The supply headers carry semi-circular limbs each with its separate damper control, these limbs being designed with high velocity slots throughout the entire length to ensure air movement across and through the work. The slots, also, are adjustable throughout their entire length. The recirculating header is complete with proportioning sliding plate dampers, and it will be appreciated that the complete circulating system both on the supply and recirculating sides is completely flexible and permits of adjustment to ensure equal temperature conditions throughout the whole of the load space. The final temperature head is limited, due to the large volume of air in circulation, and it is possible, therefore, to ensure that control temperature is not exceeded, since there is no possibility of thermal storage in the design, though the unit is thermally highly efficient and, consequently, when the control comes into operation, the effect is immediately felt on the load.

The controls fitted to this particular unit comprise a Short and Mason time schedule controller of the pneumatic type, the time temperature cycle being a predetermined one. The control valve is a reverse acting spring-loaded diaphragm type valve, and the system is a fully floating one—that is, as the control temperature is reached the control valve commences to close, gradually metering the supply of gas to the system until control point is reached. Similarly, when the control calls for gas, a gradual opening of the valve occurs as the temperature falls, thus any sudden gas surge with a quick temperature rise is completely obviated. A flame failure control is also fitted in this unit, of the "Protectoglo" type, which comprises a control relay incorporating thermionic valves with a flame electrode and electrode unit fitted to the front of the combustion chamber, the electrode being through both main and pilot flames. A push-button station is also fitted together with magnetic valves in both main burner and pilot burner lines.

When a condition of no-flame occurs in the combustion chamber, then the electrical circuit through the relay is broken and both main and pilot valves instantaneously close. Upon re-lighting, the push-button station is depressed, which by-passes the control relay to the pilot magnetic valve, energising this valve and allowing it to lift so long as this push button is depressed. When a flame has been established on the pilot burner, then the system is energised and the main magnetic valve will also lift, the main burners lighting from the pilot.

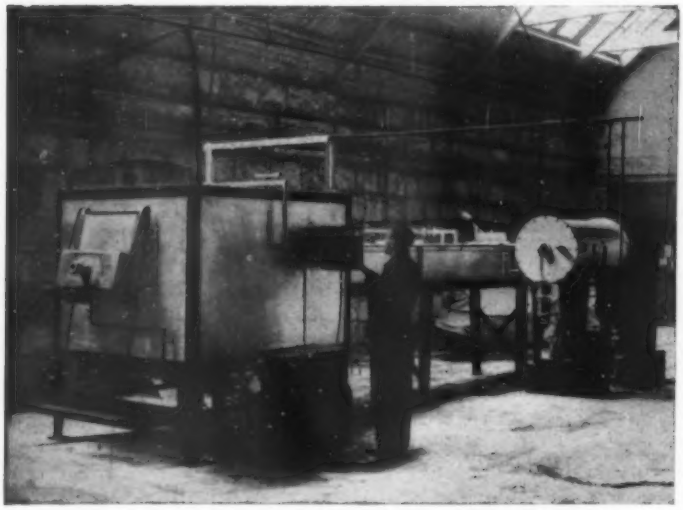


Fig. 13.—Semi-continuous controlled atmosphere furnace for bright annealing.

The furnace is fitted with a specially designed lid-lifting unit, and is also complete with an electrical hoist, runway and quench tank. It was designed for maximum temperatures of the order of 550° C., the working temperatures being between 495° C. and 535° C., and the temperature difference when working at these temperatures does not exceed plus or minus 3° C. at any part of the working chamber.

Salt-baths are used to a considerable extent for the treatment of light alloy components ; they are especially applicable for normalising airframes, and a typical plant for this purpose is shown in Fig. 10. This is a Hinds-Griffiths design, and the dimensions of the bath are 18 ft. by 3 ft. by 4 ft. deep. Electrically operated overhead lifting gear is provided, the work being loaded in a basket of special construction and the whole immersed in the salt-bath. After a period of heating the basket is lifted from the salt-bath and lowered into the water-quench tank forming part of the equipment. Spare baskets are loaded, so that the operations can be as continuous as possible. In this instance, the dimensions of the salt-bath is governed by the size of the airframes treated, but it is interesting to note that the fall in the temperature on the immersion of a charge is less than 10° C., and even temperature is maintained throughout the entire volume of the bath.

A gas-fired air-circulated oven for age-hardening light alloy aeroplane parts is shown in Fig. 11. Units of this have been designed by Controlled Heat and Air, Ltd., for working temperatures up to 230° C., although the normal operating temperature is between 175° and 180° C. The oven has a length of approximately 48 ft. ; throughout its length a drag-line conveyer is arranged, comprising a single-strand hollow-bearing pin chain fitted with drag plates at approximately 3 ft. pitch. Trolleys are run in channel tracks to carry the work to be heat-treated.

The circulating system comprises two specially designed combustion chambers, each combustion chamber comprising a circular insulated casing. The burner is a single unit of the luminous flame pattern which burns into a circular combustion tube with cast-iron baffle-plate and adjustable fresh-air inlet. A large capacity multivane type circulating fan is coupled to the back to each combustion chamber and delivers into a system of ducting arranged underneath the conveyer track. This ducting is designed with perforated top plates with high velocity slots to ensure correct air distribution throughout the entire oven length, and also a high degree of turbulence in order to prevent stratification and under working conditions it has been found that the temperature difference at any part of the working space, and in the entire length of the oven, does not exceed plus or minus 2½° C.

The conveyer system is designed for intermittent operation, and a special adjustable timer is supplied, designed to indicate to the operator when the next load shall be placed in the oven, by the rising doors at both loading and unloading ends of the oven being raised and the conveyer motor start-button being depressed, then the conveyer will move forward one pitch, when by means of limit switches, the conveyer drive motor is tripped out and is brought instantaneously to rest by means of a magnetic brake. To ensure that the system cannot be started up when the unloading door is still closed, a further limit switch is arranged at the unloading end of the oven, which is kept open by the last truck in the oven section. By the door being raised, and this truck removed, then the motor circuit is completed, and the conveyer system can be started.

The controls to each combustion chamber comprise a Leeds Northrupp "Micromax" unit; together with flame failure controls of the "Protectoglo" pattern.

A heat-treatment oven of special design is that shown in Fig. 12 ; it is used for the treatment of magnesium alloy castings at temperatures up to 425° C. For the particular purpose this oven is designed it is essential that at the control temperature the free oxygen present in the circulating air stream should be below 2%, and special precautions are taken in the design of the casing to ensure that this is air-tight. The rising door is fitted with cam type door clamps and is sand-sealed after closing.

The circulating system comprises two headers arranged along both sides and at the top of the working chamber, these headers being fitted with downcomers tapered in section and with high velocity slots capable of adjustment along their entire length. Each downcomer is fitted with a proportioning damper fitted in the spigot to the main header. The recirculating duct is arranged along the centre top of the working space and is fitted with proportioning sliding-plate dampers. The entire circulating system is completely flexible and is so designed that a turbulent atmosphere is created throughout the working space, which ensures equal temperature conditions. A special connection is taken from the fan discharge to the point where the fan-shaft enters the fan casing in order to form an efficient seal and to prevent the ingress of fresh air into the system. Great care has been taken in the design of the expansion joints in the duct system to ensure that these remain air-tight under all conditions.

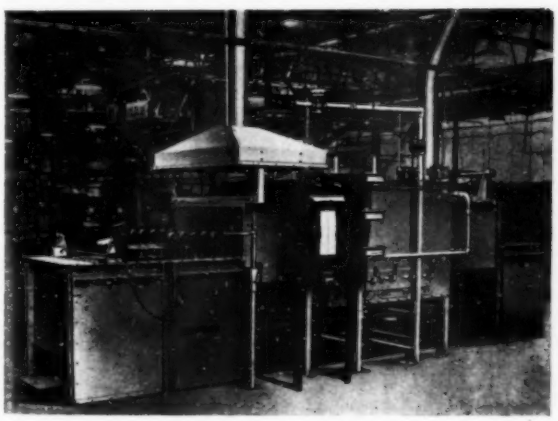
The oven is designed for firing by means of a pre-determined gas/air mixture, and in practice it has been found possible to so control the ratio that at the critical working temperature the amount of oxygen present in the system is within the required limits. The thermo-static control comprises a Short and Mason time schedule controller of the pneumatic pattern, operating a reverse acting spring-loaded diaphragm type valve fitted in the main gas line, and in addition a check Cambridge recorder of the pyrometric type is also fitted, together with a continuous CO_2 and CO plus H_2 recorder.

New Bright Annealing Plant

Several designs of furnaces have been developed for copper brazing, bright annealing, and bright hardening, in which controlled atmospheres are employed. The semi-continuous furnace shown in Fig. 13 is typical of this type. The components to be treated are loaded on trays which are pushed through the furnace, the rate depending upon the weight of work. Suitable protective atmosphere is obtained from a standard atmosphere - producing plant operating either on town's, producer, or coke-oven gas, as shown on the right of the illustration. Semi-continuous furnaces of this type by Electric Resistance Furnace Co., Ltd., are normally designed for hand operation, and on this account the maximum output is limited to 300 lb. to 400 lb. of treated work per hour.

Both continuous and semi-continuous bright annealing plants have been in use on a production basis in this country for many years. Indeed, most of the leading manufacturers of steel and copper wire, strip, tubing and sheet have installed these equipments. The installations already at work vary in size from relatively small outputs from 3–4 cwt. per hour to 2 or 3 tons per hour obtained from the large plants. The bell or top-hat type furnace equipment usually comprises one or more electrically heated bell furnaces with automatic temperature control, a number of insulated hearths or bases with gas-tight containers and a plant for the production of the protective atmosphere.

Fig. 14.—A hot-air circulated conveyer furnace designed with preheating, heating, soaking and air-cooling zones.



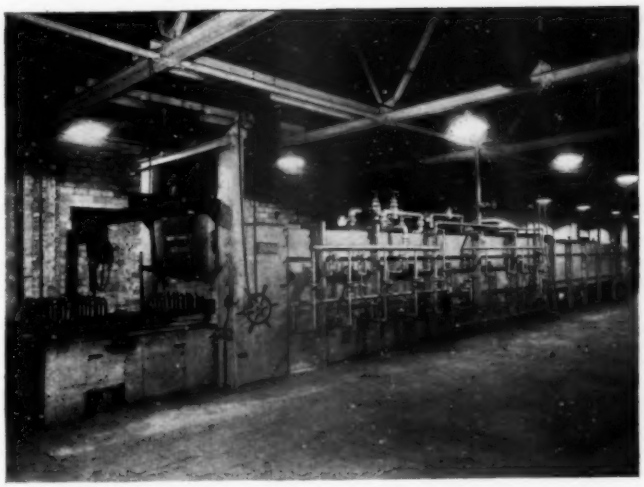


Fig. 15.—A modern type of continuous gas-fired annealing furnace.

A modern plant has recently been installed by Messrs. Electric Resistance Furnace Co., Ltd., for bright annealing high-grade wire. The main requirements being absolute freedom from decarburisation and bright finish. This installation comprises three furnace bells, each rated at 120 kw., eight charge bases complete with containers and charge carriers, two rest positions for the furnace bells, fully automatic temperature equipment, and I.C.I. regenerative ammonia type burner equipment for the production of the protective atmosphere.

Each base has working dimensions 3 ft. 6 in. diameter × 6 ft. high, and is fitted with the patented Gill propeller type fan which ensures rapid and uniform heating of the charge and also assists in rapid cooling. The fan-shaft seal is of a special design which prevents any leakage of atmosphere down the fan-shaft and at the same time eliminates all the maintenance troubles common to the packed gland type of seal.

Special attention has also been given to the sealing arrangements between the container and the charge base, again to prevent heat and atmosphere leakage. Probably the most important point in the design is the construction of the bases themselves. These are completely metal clad, a desirable feature if freedom from decarburisation is to be assured. The design which has an open refractory heart may result in decarburised work due to air and water becoming entrapped in the brickwork. Again, the base and container design is such that there is a minimum amount of distortion at high temperature.

When the furnace bell is lowered over the charge base a special plug-and-socket arrangement energises the furnace heating elements. This eliminates completely the necessity of having unwieldy flexible training cables.

Controlled heating, controlled soaking, and controlled cooling is another feature of this plant. Depending, of course, on the nature of the charge, it can be brought up to the annealing temperature, maintained at temperature for a soaking period and then cooled off at a predetermined rate—all under automatic control. The cycle can be modified at will to suit the class of material being treated. Finally, the layout is such that all sections of the plant are readily accessible and shop

conditions for the operators are very much better compared with older methods of annealing.

Hot-Air Conveyer Furnace

Many heat-treatment furnaces are equipped to provide forced air circulation, and an interesting design of this type of furnace arranged to continuous treatment is shown in Fig. 14. It is a Hind-Griffiths design, and incorporates pre-heating, soaking, air-cooling and water-quenching zones, and is fitted with a variable speed conveyer which operates between heat-resisting guides located inside the furnace. Heated by gas through special burners, each of which fire into a separate pocket down each side of the furnace, the atmosphere of the heating zone within the furnace is balanced by the introduction of the hot products of combustions and the discharge of a similar volume to the preheating zone. It is designed for temperatures up to 700° C.

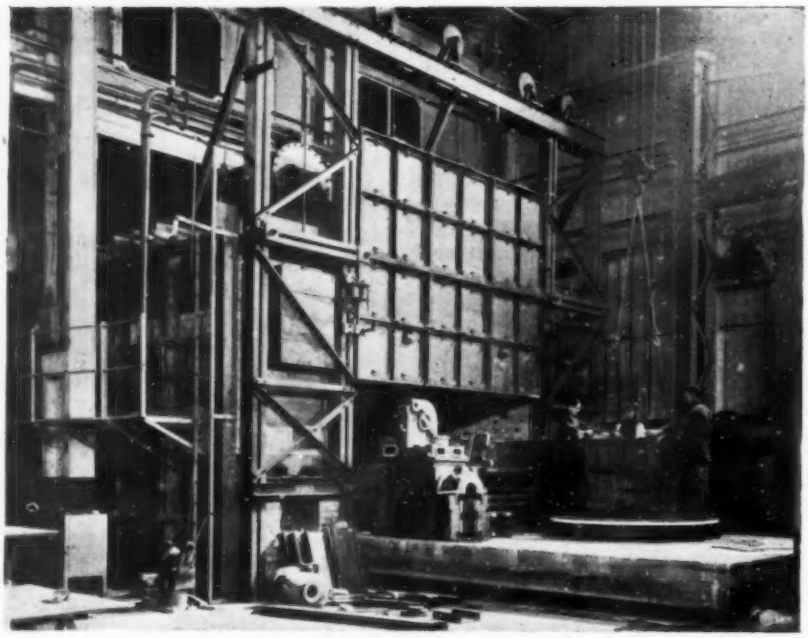


Fig. 16.—Large stress-relieving furnace in regular operation.

Annealing Furnaces

Annealing furnaces may be of the batch, semi-continuous, or continuous types, and may be with or without atmosphere control. The installation of a plant for continuous annealing must be justified by a steady demand for its product, but the rate of treatment can be readily controlled to promote uniform conditions, and this is of considerable advantage. A recently installed furnace of this type is shown in Fig. 15. It is fired by town's gas and is used for annealing shell forgings. It is 4 ft, 6 in. wide with a heating zone 11 ft. long, soaking zone 14 ft. long, and a cooling zone 24 ft. long.

The material to be treated is loaded on the heat-resisting trays which are pushed through the furnace on skids by means of an electrically driven pusher at the charge end of the furnace, and the shot is heated to 820° C., soaked at this temperature, and discharged from the cooling zone at about 300° C. The furnace, which was designed and constructed by British Furnaces, Ltd., is lined with 9 in. of refractory backed up with 4½ in. of insulating material, the whole being enclosed in a heavy mild-steel casing.

The burner equipment is of the automatic proportioning single-valve control type, using low-pressure gas with air at a pressure of 1 lb. per sq. in., and the burners are arranged to fire both above and below the work being treated. Automatic temperature control is provided for the heating and soaking zones. The furnace deals with work at the rate of 1,020 lb. nett per hour on a gas consumption of 1,650 cub. ft. of gas per hour, which represents a net heating efficiency of 28%, whilst the gross efficiency is 43%.

Full annealing when carried out to obtain grain refinement in combination with high ductility, necessitates heating to above the upper critical point followed by slow cooling, but frequently the operation is carried out to relieve internal stresses caused by previous operations when the temperature of treatment is usually in the neighbourhood of 850° C.

Furnaces are specially designed for stress-relieving work of this character, and a recent installation of such a furnace is shown in Fig. 16. Designed and constructed by the Dowson and Mason Gas Plant Co., Ltd., for Metropolitan Vickers Electrical Co., Ltd., to whom we are indebted for the illustration, it was originally erected for the use of fuel oil, but before being put into operation was converted for the use of town's gas.

This stress-relieving furnace is 20 ft. long, 14 ft. wide, and 10 ft. 9 in. high. It carries five top burners and four bottom burners on each side. As the maximum working temperature is in the region of 850° C., the combustion chambers originally designed for oil are quite suitable when town's gas is used. The arch is of the "Liptak" type and five agitating fans are fitted in the roof. The temperature is automatically controlled from two points on the roof and recorded on other four points. The outlet ports from the furnace carry the waste products directly into two receiving tubes built on each side of the furnace and each of the ports is fitted with a regulation damper. This furnace is in regular operation.

Conclusion

It has only been possible to give a cursory review of some of the developments in the application of gas carburising; the use of controlled atmospheres; forced circulation for more uniform heating; salt-baths for hardening high-speed steel tools and for the heat-treatment of light alloy components; and in annealing and stress-relieving furnaces. Attention has also been directed to the possibilities of induction heating which is successfully applied to a number of heat-treatment processes.

Some Developments in the Hardening of Ferrous Alloys

By A. E. Shorter, M.B.E., M.I.Mech.E.

Flame hardening on the lines developed by the author has advanced from an obscure metallurgical idea to an established practice. The technique developed has improved the facilities for producing the degree of hardness desired, within the possible range, on a automatic basis. Experimental work is discussed, showing some of these developments and how they are applied in practice.

THE hardening of steel has been the subject of considerable study, and whilst the reasons for the production of hardness on quenching are not yet fully understood, in practice the operations required to produce this property are known and have been applied since the early days of steel manufacture. Developments have been effected in the methods employed and in the control of heating and of cooling to promote the degree of hardness within the possible range of the particular steel treated. It is in connection with further investigation of one of these methods that these notes are primarily concerned.

In the first issue of this journal reference was made to a new method of hardening the wearing surfaces of steel gearwheel teeth. The method consisted in heating the surface to be hardened, by means of an oxy-acetylene flame, and immediately quenching with water. The method was operated mechanically, and became known as the Shorter process of surface hardening. From time to time since, reference has been made to developments in mechanical devices to improve or facilitate the method in practice.

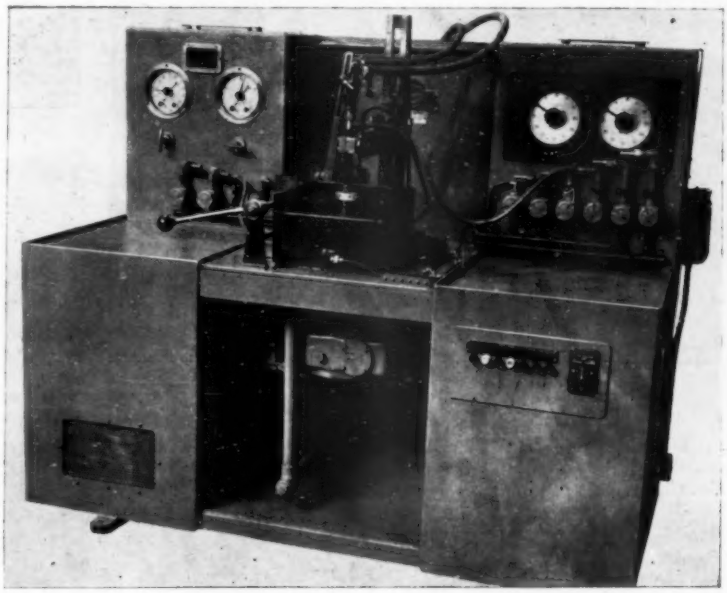


Fig. 1.—Shorter N. 3 automatic surface-hardening machine.

The earliest types of machines developed for this work were for straight-line operation, and, as mentioned, were first used for hardening the tooth faces of gearwheels, but the latest machines embody some new technique in Shorter process hardening which has gradually widened its scope during recent years, and machines have been designed and are in operation that can deal with large or small areas on a mass production basis. A machine of this type is shown in Fig. 1. It has been used to carry out the work described later, and particulars concerning this machine will be of interest.

The machine provides for heating the parts with oxy-fuel-gas burners and quenching with water, colloidal or air, whichever is most suited to the material under treatment. Both the heating and the cooling (quenching) are timed with synchronous clocks which work in conjunction with the gas and water valves. The valves are connected to two special Budenberg gauges which can be so set that if the gas pressures vary outside the correct working pressure limits, the contacts immediately shut down the whole plant. In this way the work is not dependent upon the operator or any fluctuation in gas pressures. The machine is controlled by push-button, and is fully automatic in operation. Many important features cannot yet be released, but it is interesting to refer to some results that are being achieved, an example of which is the steel hammer head shown sectioned and etched in Fig. 2. Also illustrated in Fig. 2 are macro-photographs of the sections showing the location of positions of microphotographs reproduced to show the structure resulting from this treatment.

It will be seen in Figs. 3 and 4 that the face and peen of the hammer head treated by this process have been brought to a martensitic structure, and that gradually this structure merges through troosite to the pearlite and ferrite to the normal core structure of the material, shown in Fig. 4c.

The actual hardening time of these hammer heads on a single-unit machine is 1 min. 30 secs., and it will be noted that the peen end has been treated somewhat differently from the face. The treatment given is considered to be ideal for this form of head. It will be

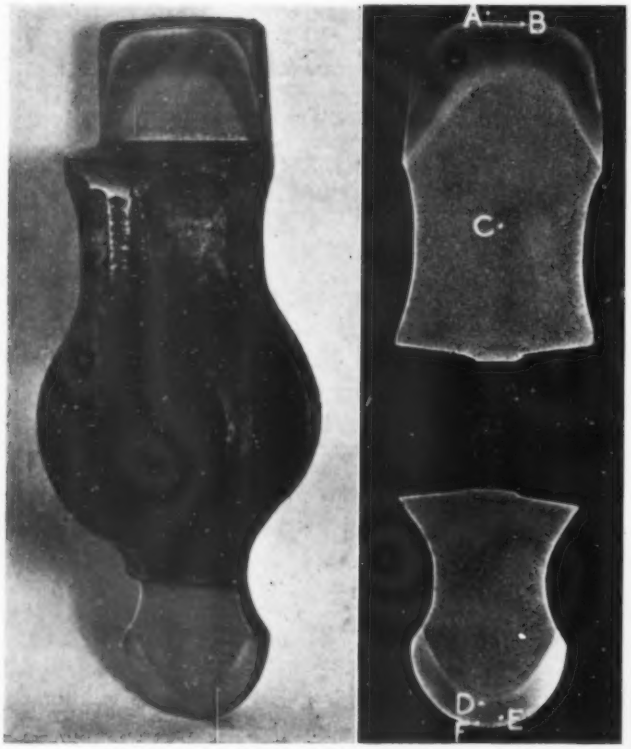
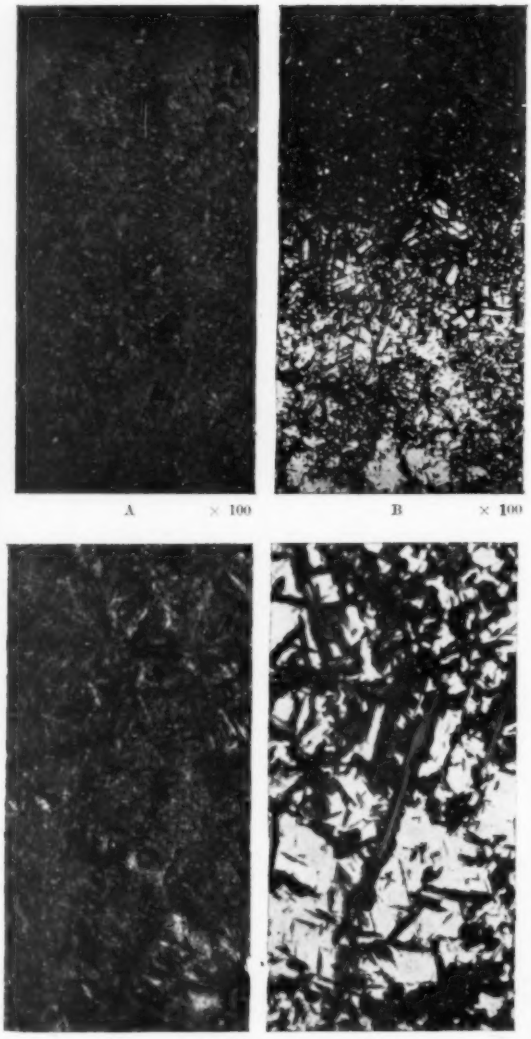


Fig. 2.—Steel hammer head, sectioned and etched to show result of the treatment. × 1.

appreciated that machines fitted with jigs to harden a number of hammers simultaneously would greatly reduce the time of treatment per hammer, and a considerable number can be treated at one time on a suitably jigged machine.

For components subject to shock in service, it is generally recognised that any hardening treatment to which they are submitted should not produce brittleness. This is especially important in the case of hammer heads, and therefore some consideration must be given

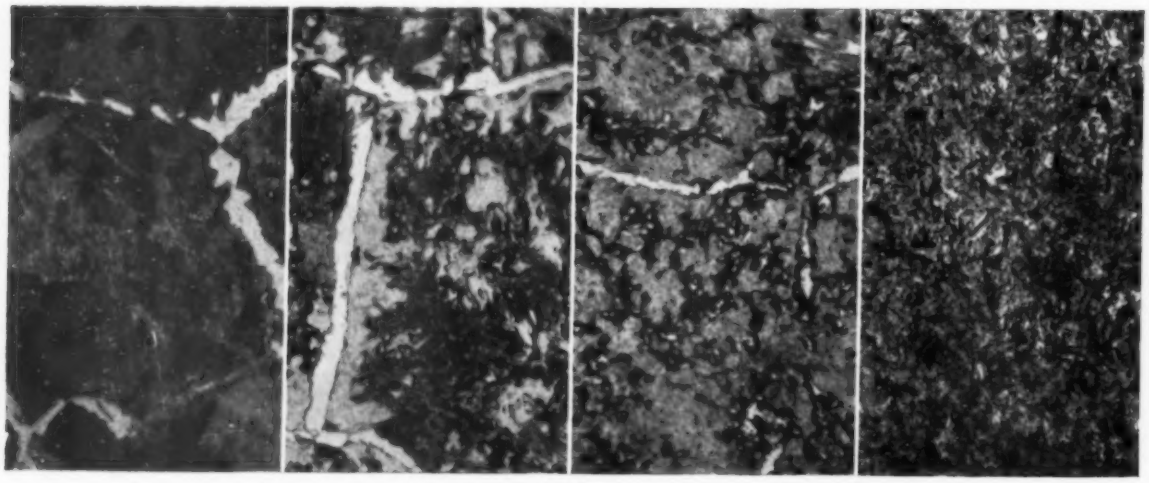


A × 100 B × 100

A × 500 B × 400

Fig. 3.—Showing structure at positions A & B (Fig. 2)

Fig. 4.—Showing structure at positions C. D. E & F (Fig. 2)



C × 500 D × 500 E × 500 F × 508

to the grade of steel used in relation to the hardness desired.

The hammer head shown in Fig. 2 was made from a normalised 0·5 to 0·55% carbon steel. Such a steel is capable of yielding a high hardness value when heated and quenched from the critical temperature by this process. It can, for instance, be surface hardened to a value as high as 800 V.P.N. But with a steel of this type such a hardness would obviously render the steel liable, under shock conditions, to expoliate and would lead to disappointing results in service. An examination of the hardness test results given in Tables I and II for the points indicated in the macrophotograph, Fig. 5, show that the maximum surface hardness of the face and peen of the hammer head under discussion has not been produced. Had the treatment given maximum hardness, the serviceability of the hammer would have been greatly impaired.

In any method adopted, it is necessary to adjust the treatment to promote the desired properties. With this in mind, the Shorter machine was set with the object of producing a tempered martensitic structure and at the same time a heat-treatment procedure embracing a large portion of the hammer head, sufficient to give stability and shock-resisting properties, such as the diamond hardness tests clearly indicate.

It will be noted that surface hardness of 446 V.P.N. at the face end to the hammer is gradually reduced through the 300 range to the hardness of 224 V.P.N. of the normal structure. The opposite end—the peen end—of the hammer was hardened to a higher value, but it will be seen that there is a fall in hardness at the surface, due to slight decarburisation ; the hardness value increasing at 1·14 mm. from the surface to 627 V.P.N., and gradually falling to a hardness of 230 V.P.N. at a position 7·77 mm. from the surface. When considered in relation to the position of the hardness tests, these figures indicate the gradual change in values in relation to the depth treated.

The foregoing is an example from many tools to which similar technique can be applied to obtain the hardness desired. The same control of treatment and uniformity of result can be obtained, and, apart from the actual setting, the effect of the human element is eliminated.

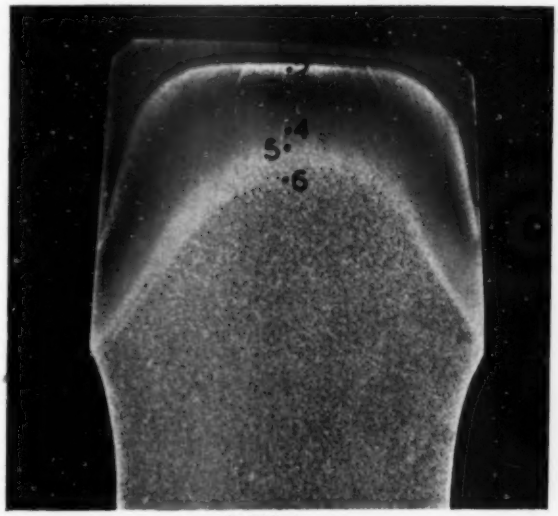


TABLE I.
FACE END OF HAMMER.
Vickers' Diamond Hardness Tests.
10 kg. Load.

Impression No.	Distance from Surface.	V.P.N.
1	0·880 mm.	446
2	1·820 mm.	429
3	3·370 mm.	317
4	6·470 mm.	266
5	7·750 mm.	254
6	10·260 mm.	224

TABLE II.
PEEN END OF HAMMER.
Vickers' Diamond Hardness Tests.
10 kg. Load.

Impression No.	Distance from Surface.	V.P.N.
1	0·500 mm.	599
2	1·140 mm.	627
3	1·660 mm.	613
4	3·950 mm.	394
5	5·460 mm.	230
6	7·770 mm.	230

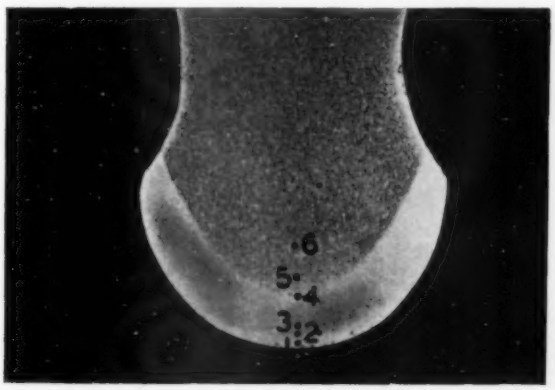
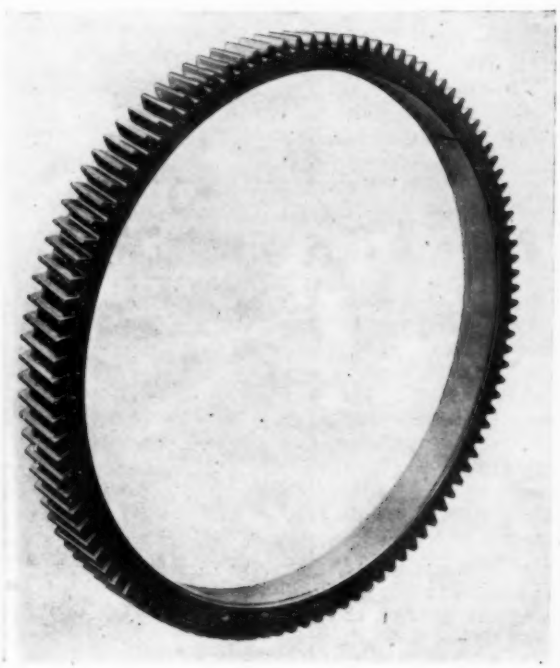
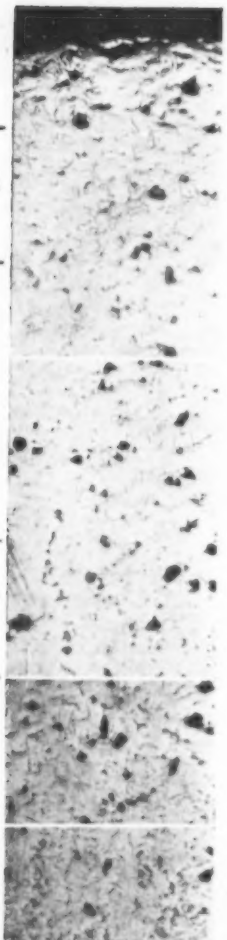


Fig. 5.—Enlargement of macrograph in Fig. 2, showing the positions at which hardness tests were made, the results of which are given in Tables I and II.

Fig. 6.—Engine starter ring with an internal diameter of 15¾ in., $\frac{7}{8}$ in. × $\frac{5}{8}$ in. in section and having 138 teeth successfully hardened.





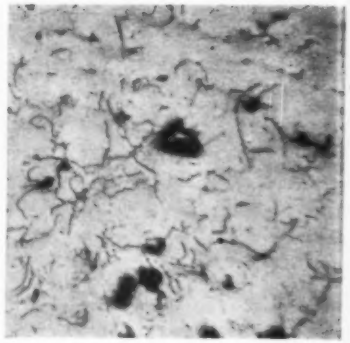
Many manufacturers of fools of various types appreciate the skill of their heat-treaters, and it is true that many components are treated by skilled operators with very consistent results, but the art of the intelligent and skilled heat-treater is not easily handed on. It is not surprising, therefore, that the tendency is ever towards the perfected instrument of control, especially in these days of mass production, when uniformity of product is essential to industry.

The example given is typical of many small components which have provided difficult hardening problems, particularly light parts required in large quantities which, because of the treatment required, have been handled individually. In many industries, notably the motor and aircraft industries, and especially in the textile machinery trade, hardening problems frequently arise that are not satisfactorily solved, with the result that certain products of the hardening shop continue to be a source of trouble.

A component which has long been a source of trouble is the engine starter ring shown in Fig. 6. This ring, which takes the shock of the starter pinion, carries small pitched teeth. These rings are required to be shrunk on to gear bodies or centres, and for this purpose they must be produced to fine limits. Thus, little or no allowance can be left for ovality or distortion, and some extraordinary means of holding the rings for heat-treatment purposes render them a bottleneck in mass production.

This difficulty has been solved on the machine illustrated in Fig. 1, on which the average starter ring can be readily mounted and hardened on the crash ends, sufficiently far down the tooth to give adequate resistance to wear. The slight dimensional change which results is well within grinding limits, and the rings can be quickly and easily shrunk on to their centres. The whole hardening operation occupies less than *one minute*, and 60 rings per hour can be treated with precision. The same machine permits tappet screws to be hardened on the end face without affecting the threads and at a rate comparable with the rate of flow of production. These developments enable Shorter hardening machines to be placed within the machine-shop and into the production line, so that parts can pass from machine to machine until they reach the hardening machine and thence to the grinders and on to the assembly belts. Several of these machines are now facilitating production, since they remove the necessity for machined parts leaving the machine-shop for hardening in furnaces, and thus avoid any interference in the flow of parts in the production line.

This process can be applied to a wider range of steels and irons than is generally appreciated. Keeping in mind that it depends on the hardening elements in the material, it will be appreciated that all the carbon steels from 0·25 to above 1·0% come within its range. The results in hardness vary with the carbon and also with any alloys which may be present. It is therefore possible to select steels suited to different types of service, when high hardness and resistance to wear are necessary ; the higher carbon steels are generally preferred, but when shock-resisting properties are of paramount importance the milder carbon steels are usually selected.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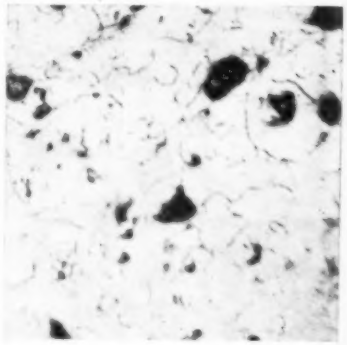
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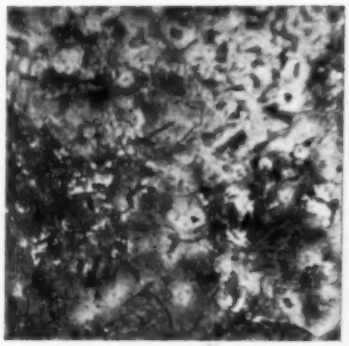
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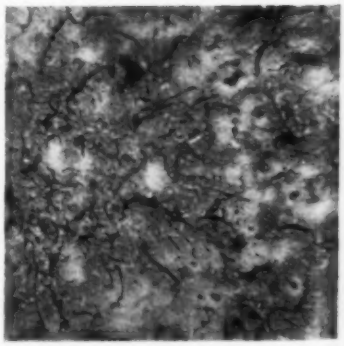
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Fig. 7.—Hardening a molybdenum cast iron, showing the gradual change in structure from the treated face to the core.
The series of micrographs on the left is reduced from an original 2½ times larger.

The technique of this process is being applied in a number of instances where the normal case-hardening practice causes so much distortion that the parts are rendered useless ; this difficulty has been overcome by carrying out the carburising procedure *without quenching*. Local areas required to be hardened have been successfully treated by the Shorter process with no appreciable distortion. This method has the advantage of eliminating the necessity of copper coating those areas not required to be case-hardened.

The Treatment of Cast Iron

It is not generally appreciated that cast irons can be successfully hardened. This applies to all cast irons which contain sufficient combined carbon to induce hardness, when heated to critical temperature and quenched. Most good-quality cast irons, including grey irons, nickel irons, molybdenum irons, Meehanite, and semi-steel are readily hardened by the Shorter process ; even white heart malleable cast iron can be successfully treated, when the decarburised surface has been machined off.

Some experimental work on a molybdenum cast iron was carried out by this process, and the results are not without interest. A molybdenum cast iron was selected because it was known to offer effective hardening results, and the contents of this element was 0·80%. Tests were made on 1½ in. square bars, 13 in. long, one face of which was hardened in a standard machine. The total effective depth of the treatment was approximately 0·18 in., although for general purposes it is not usual to harden to this depth. The hardness values obtained were between 500 and 650 V.P.N. As will be seen from the microphotographs in Fig. 7, the structure changes gradually from the martensitic structure near the face to the normal pearlitic structure of the bar. Although the gradual change in structure between the face and the core is well defined with a molybdenum cast iron, the process can be applied successfully to a wide range of grey and alloy cast irons.

Use of Permeable Refractories for Furnace Construction

By R. H. Anderson, M.Inst.F., D. C. Gunn, B.Sc.(Eng.) M.Sc., and A. L. Roberts, Ph.D.

Much attention has been given to the improvement of refractories in recent years, especially to insulating refractories or hot-face insulation. A more recent development is the use of the permeable characteristics of refractories in order to increase furnace efficiency. The authors discuss this important development and report the results of experimental work in a recent paper before the Institute of Fuel. In this abstract particular reference is made to the application of permeable linings to a treatment furnace.

INSULATING materials for furnaces have been largely obtained from diatomite, used either in the calcined or natural state. Whilst thermal conductivity of such materials is low, its refractory properties are such that it cannot be used for the line of furnaces, except at comparatively low temperatures. Hence a development occurred which, to some extent, reproduced artificially what nature had performed in diatomite—the inclusion of small air cells. Carbonaceous material was mixed with fireclay, the shapes made, dried and fired. The result was a firebrick possessing valuable insulating properties and yet being usable at much higher temperature than diatomite. Such material has become well known under names such as insulating refractory or hot-face insulation, and has been widely and successfully used on the hot face of fuel-fired and electric furnaces working up to 1,200° C. or even higher.

This material is highly permeable to gas flow, and it is this characteristic with which the authors are chiefly concerned, demonstrating, as they have done by experimental work described in their report, that the property of high permeability in refractories can be used to achieve a marked increase in furnace efficiency, providing in fact a new method of waste heat recovery. All the experimental work has been carried out with town gas, thus the discussion is concerned with furnaces fired with a clean fuel.

Assuming that a furnace is built using a permeable refractory for its construction and also that a fuel is being burnt in the furnace and that the products of combustion from the fuel burnt in the furnace escape from a normal flue system, then, if the air pressure within the furnace differs from atmospheric, gas flow through the structure will occur. If the pressure within the structure is greater than atmospheric, gas flow outwards will occur ; on the other hand, if the pressure is negative within the furnace, air flow inwards will take place. The tendency of outward gas flow may be towards decreasing the temperature gradient through the structure, and hence decreasing the heat conducted through the brickwork. The opposite effect will clearly occur when air passes inwards, exercising a cooling effect on the wall.

It is probable that the total quantity of heat transferred by walls is increased by outward gas flow. The important point is that the flow is in two components : the *conduction* loss, plus or minus the *convection* loss, and that this convection loss consists of heat contained in gases *after they leave the combustion chamber*. The effect of the outward passage of gases is to tend to decrease the temperature gradient and, therefore, the *conduction loss*. This is achieved by *waste heat*. If the conduction losses are therefore being supplied in part by waste heat, the fuel consumption of the furnace must suffer a reduction if the same temperature conditions are to be maintained.

What reductions in fuel consumption can be gained by deliberately causing all the products of combustion to leave a furnace through a permeable wall?

A furnace working in such a condition that for a given rate of heat input the temperatures at all points remain constant is said to be in a state of equilibrium. Consider such a furnace constructed from materials of uniform thermal properties and let it be of the type where no form of heat recovery from the waste gases is used.

If t_1° F. is the temperature of the inner face of the lining, and t_2° F. is the temperature L inches inside the wall from the inner face, the heat transmitted through unit area of wall will be given by :—

$$Q_{cw} = \frac{k}{L}(t_1 - t_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where Q_{cw} is the heat transmitted in B.Th.U./hour, and k = coefficient of conductivity of the material.

If it is assumed that the flue gases leave the furnace at a temperature of t_1° F., and that their specific heat is s_1, the heat carried away by the products of combustion will be given by :—

$$Q_{cp} = \frac{Q_A}{C} V s_1 t_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where Q_A = gross heat input to the furnace in B.Th.U./hour, C = calorific value of fuel in B.Th.U./cub. ft., V = volume of products of combustion from 1 cub. ft. of gaseous fuel.

The gross heat input to the furnace will be given by the sum of (1) and (2) :—

$$Q_A = Q_{cw} + Q_{cp}$$

$$Q_A = \frac{k}{L}(t_1 - t_2) + \frac{Q_A V s_1 t_1}{C}$$

Rearranging the equation :—

$$Q_A = \frac{\frac{k}{L}(t_1 - t_2)\,C}{C - V s_1 t_1}$$

If the furnace is subject to a steady load of B, B.Th.U./hour.

$$Q_A = \left\{ \frac{\frac{k}{L}(t_1 - t_2) + B}{C - V s_1 t_1} \right\} C \quad . \quad . \quad . \quad . \quad (3)$$

Consider now the case of a furnace constructed on similar lines, differing only in that the products of combustion, instead of leaving the furnace through a flue in the combustion chamber, are forced to leave the furnace through the walls, which are made of a material similar in thermal properties to the previous furnace save that they are permeable to gas flow.

The cellular nature of such material presents a vast area over which heat transfer can take place (of the order of 1,000 sq. ft. per cub. ft. of material). It may therefore be assumed that for all practical purposes the temperature of the gases within the material will be the same as that of the material itself.

Hence, with similar symbolism to that used above and causing the gases to leave the permeable material a distance L inches from the inside face, we have the following :—

The heat lost through the wall will be—

$$Q_{bw} = \frac{k}{L}(t_1 - t_3]$$

The heat carried away up the flue

$$Q_{bp} = \frac{Q_B}{C} V s_2 t_2$$

If the furnace is subjected to a steady load of B, B.Th.U./hour, then the fuel required is given by—

$$Q_B = Q_{bw} + Q_{bp} + B$$

$$= \frac{k}{L}(t_1 - t_2) + \frac{Q_B V s_2 t_2}{C} + B$$

Whence,

$$Q_B = \left\{ \frac{\frac{k}{L}(t_1 - t_3) + B}{C - V s_2 t_2} \right\} C \quad . \quad . \quad . \quad . \quad (4)$$

Notice how (4) differs from (3). We have t_3 instead of t_2 in the numerator and t_3 instead of t_1 in the denominator, we have s_2 instead of s_1 in the denominator. Now t_2 is greater than t_3, hence the numerator in (4) is less than that in (3). Furthermore, s_2 and t_2 are less than s_1 and t_1, therefore the denominator is greater. Hence Q_B is less than Q_A—i.e., furnace B is more efficient than furnace A.

We can select t_1, but t_2 is dependent on t_1 and the furnace conditions. We can calculate it by equating the heat flow in the wall section, but it is a difficult operation and some very wide assumptions have to be made. In order therefore to simplify the argument at this stage we are going to make the assumption that t_2 is very little different from t_3 and that $s_2 = s_1$.

The value of the saving involved then is given by

$$P = 100\% \times \frac{Q_A - Q_B}{Q_A}$$

$$= \frac{\frac{\frac{k}{L}(t_1 - t_2) + B}{C - V s_1 t_1} C - \frac{\frac{k}{L}(t_1 - t_2) + B}{C - V s_1 t_2} C}{\frac{\frac{k}{L}(t_1 - t_2) + B}{C - V s_1 t_1} C} \times 100\%.$$

$$= 1 - \frac{C - V s_1 t_1}{C - V s_1 t_2} \times 100\%.$$

Assuming that V = 4·8 cub. ft./cub. ft. of gas burned s_1 = 0·023 B.Th.U./cub. ft./°C.

$$\frac{P}{100\%} = 1 - \frac{C - 0{\cdot}11\ t_1}{C - 0{\cdot}11\ t_2}$$

Having indicated that an increase in efficiency can be expected, the authors consider the practical problems involved in applying the principles to practice. The inner lining of a furnace, incorporating this principle, should be permeable to a sufficient extent to permit the exhaust of all waste gases with a reasonable suction on the collecting chamber or pressure in the furnace. Permeable material being unsuitable where mechanical abrasion takes place, such parts must be covered with or replaced by suitable dense refractory. The inner lining must be supported in some way from the outer structure. Thus, the first step is to find materials sufficiently permeable and at the same time having satisfactory mechanical and refractory properties.

The Permeability of Refractory Materials to Gases

Most refractories are permeable to gases, the degree of permeability varying widely from one material to another. This property is evaluated by the permeability coefficient, defined as the volume of gas which will pass through unit area of material of unit thickness in unit time under unit pressure differential. In this report the permeability coefficient is expressed in British units, and

represents the number of cubic feet of gas passing per hour through 1 sq. in. of material 1 in. in thickness under a pressure difference of 1 in. water gauge.

Apart from the variations in permeability of different materials, the variation of permeability with temperature is of obvious importance, particularly with regard to the present application of highly permeable materials.

In experiments on a number of commercial materials, the permeability coefficient was found to decrease as the temperature was raised ; the *relative* decrease was almost the same for all the materials, and was independent of the absolute permeability value at room temperature. Thus, the permeability coefficient was reduced to approximately 0·5 at 500° C., and to 0·4 at 850° C., of its value at atmospheric temperature. The change of permeability with temperature was evidently a function of the gas, and not the refractories, and it was found that the observed alteration corresponded almost quantitatively with the increase in viscosity of the gas. Extension of the work to higher temperatures was prevented by experimental difficulties, but the reduction in permeability resulting at 1,000° to 1,350° C. was calculated on the assumption of the quantitative relationship between permeability and the viscosity of the gas. In this paper the same method has been used for calculating the permeability coefficients at high temperatures from data directly determined at room temperature.

The principle of the permeable-lined furnace appeared to necessitate the development of a material having as high a permeability as can be obtained, consistent with adequate mechanical strength. Initial trials with the experimental furnace on which the new principle was tested indicated that the permeability of the lining material should be of the order of 4 to 5 at room temperature, which would imply values of approximately 1 to 1·5 at a working temperature of 1,200° C., if all the products of combustion were to be exhausted through the lining under a reasonable pressure difference. It seemed probable, however, that the permeability would be increased by unavoidable leakage through joints and cracks, and data obtained in the tests on the industrial installations showed that the effective permeability of the lining as a whole was as much as three times greater than that of the material itself.

Table I shows porosity and permeability data for the permeable material in comparison with typical fireclay refractories of the dense and porous insulating types.

TABLE I.

Material.	Approximate Bulk Density (lb./cub. ft.)	Percentage Porosity.	Range of Permeability Coefficient.	Cub. Ft. of Gas Passing Through 1 sq. ft. 1 ft. Thick in 1 hour for 1 in. Pressure Differential at 1,200° C.
Dense fireclay brick....	110 to 130	20 to 30	0·02 to 0·50	0·8 to 2·0
Insulating fireclay brick	35 to 50	60 to 75	0·8 to 2·5	3 to 10
Permeable fireclay brick.	40	70 to 75	5·5	22

The success of the permeable lining furnace depends on the use of refractories of high permeability attained by the development of an extremely open texture.

Experimental Work

A permeable lined furnace was built at the Fuel Department, Leeds University, and was installed in the Corbett Woodall Experimental Laboratory. It consisted of a vertical pit type furnace designed to accommodate a 60 lb. brass capacity crucible. The lining was tapered with the object of drawing more gases through the top than through the bottom, thus effecting a more even temperature distribution. The furnace was fired with an air-cooled gas and air-blast burner, manually controlled.

At first the products of combustion were withdrawn through the lining by means of an exhaust fan, but for some conditions it was found more convenient to dispense with the fan and permit the pressure in the combustion chamber to drive the products through the wall.

The results obtained on melting aluminium indicated a probable saving of 15·2% over orthodox practice. Experience of the melting tests carried out, however, seemed to suggest that they were not a true basis of comparison for the performance of the furnace, since the true temperature of the metal can be questioned, differences in thermal storage may complicate things, and degree of furnace loading will have an influence on the figures obtained. It was felt, therefore, that a better comparison would be obtained if the furnaces were tested at no load ; and tests were conducted with empty furnaces.

The No-load Tests

(1) *Orthodox Furnace.*—This was started up and allowed to run throughout the day at minimum gas rate. At the conclusion of the day, measurements were taken of :—

(*a*) Gas rate per hour.
(*b*) Lining temperature.
(*c*) Flue temperature.
(*d*) Casing temperatures.
(*e*) Flue gas analysis.

In view of the fact that the furnace settled down at 1,400° C. or thereabouts, the measurement of the waste gas temperature had to be carried out, using Fery's sodium line reversal method. A suction pyrometer was tried, but failed to stand up to the conditions. The lining temperature was measured by a disappearing filament pyrometer, and the casing temperature by contact thermocouple. This data was logged at intervals throughout the experiment, but the final results only were taken as representing the equilibrium of the furnace. The experiment was repeated for the permeable-lined furnace, and the results compared in the accompanying table. In both cases the face temperature of the lining was 1,400° C., and gas analyses showed good combustion.

—	Orthodox Furnace.		Permeable Lining Furnace.	
	B.Th.U./Hr.	%.	B.Th.U./Hr.	%.
Heat supply	122,000	100	51,700	100
Heat to flue gases	84,130	68·9	17,954	34·7
Heat to direct radiation...	6,100	5·0	970	1·88
Heat through furnace top	10,895	8·9	8,530	16·5
Heat through furnace side	8,100	6·6	11,700	22·64
Heat through furnace bottom	1,630	1·3	1,310	2·54
Unaccounted for	11,145	9·3	11,236	21·74
Total	122,000	100·0	51,700	100·0

Permeable lined furnace : 7 ft. 6 in. by 3 ft. 9 in. by 22 in.
Load : Cast steel wheels and hubs supported on cast-iron plates.
Heat-treatment : Normalising at 950° C. or 900° C.
Time cycle : 3 hours.

It will be seen that under these conditions a substantial saving of 58% was achieved. Repetition confirmed the results obtained in all cases. During the period of the

tests no trouble was experienced with the refractories, and it was felt that work could proceed on an industrial installation.

Industrial Installations

(1) *Furnace for Mechanical Charger.*—The furnace measures, internally, 7 ft. 6 in. back to front, 3 ft. 9 in. wide, and 22 in. to crown of arch. Burners are of the automatic proportioning type, firing over the load. Withdrawal of waste gases takes place through walls, back, arch and a portion of the hearth, and the necessary suction is applied by an exhaust fan. The plant was put to work in April, 1943, and it has worked consistently ever since.

Control of the furnace is by thermocouple pyrometer controller operating an electric lever motor. This latter unit controls butterfly valves in the air supply and on the suction side of the exhaust fan. A variation in air supply causes a corresponding variation in gas supply by means of the proportioning devices included in the burner equipment. The maximum gas consumption of the furnace is 2,000 cub. ft. of 500 B.Th.U./cub. ft. gas/hour, or approximately 10,000 B.Th.U./hour/sq. ft. of internal surface area. The maximum is 200 cub. ft./hour. The control operates between these limits.

From a cold start and with no load in the furnace, the controller first cuts off gas after 17 mins., during which time the furnace has attained much more than a flash heat. The same conditions are attained in 7 mins. after an overnight shut down.

The charge in the furnace consists of steel castings for a variety of transport vehicles. They have to be brought up to 900° to 950° C., and soaked to an even temperature. The load is withdrawn and placed in a cooling bay. Meanwhile, the furnace is immediately charged with a fresh load and is back on control in approximately 45 mins. The gross load in the furnace varies between 2,000 lb. and 3,500 lb., giving a hearth loading of 70 lb. to 125 lb. per sq. ft., or, on a 3-hour cycle, 23 lb. to 42 lb./sq. ft./hour.

A number of tests were taken to determine the heat requirements of the empty furnace at equilibrium. This figure was 300 cub. ft. per hour at 950° C. or 1,500 B.Th.U. per sq. ft. of internal furnace area.

Date.	Run No.	Gas Used Cub. Ft.	Temperature, °C.	Load, Gross Lb.	Gas per Gross Lb.
May 6, 1943 ..	1	3,310	950	2,630	1·26
	2	3,000	950	2,691	1·12
	3	3,000	950	2,627	1·14
May 7, 1943 ..	1	4,050	950	2,691	1·5
	2	2,700	950	2,746	0·98
	3	3,630	950	3,173	1·14
May 8, 1943 ..	1	4,000	900	2,722	1·47
	2	3,200	900	2,786	1·15
May 9, 1944 ..	1	3,700	900	2,723	1·36
	2	3,060	900	2,786	1·1
	3	2,900	900	2,723	1·06

Careful records of the gas required were made during 57 consecutive runs, and showed an average consumption of 1·25 cub. ft. per lb., which included all gas used on the furnace. This is equivalent to a thermal efficiency of 44%. The best result obtained was 0·98 cub. ft./lb. or an efficiency of 56%. A detailed idea of the performance of this furnace is given in the above Table, it includes data derived from a number of consecutive runs.

The firm operating the furnace had no other furnaces carrying out similar work, and so direct comparison cannot be drawn. So far as we have been able to ascertain, however, the performance outlined above is at least as good as the best practice with recuperative batch type furnaces. It should be added that the optimum atmosphere for the process appears to be 12% CO_2 with slight excess air, and it is on this setting that the tests have been carried out.

No clogging up of the refractories is apparent, and in spite of the severe conditions to which the furnace is subjected, no spalling and very little cracking of the lining has occurred.

Jet Propulsion for Aircraft

IN the adaptation of jet propulsion to aircraft it is noteworthy that considerable initial assistance was given by the British Thomson-Houston Co., Ltd. In September, 1931, this company supplied Group-Captain Whittle with certain data in connection with turbo compressors and superchargers operating at high speeds. During 1933, the company carried out a very comprehensive investigation of the possibilities of various gas turbine cycles from the point of view of the use of this type of prime mover for generating power.

Developments proceeded, and in January, 1936, the company was approached by Group-Captain Whittle with regard to a jet-propulsion engine for aircraft. In view of their experience gained in the manufacture and operation of turbines, successfully operated in service at an initial temperature of 1,000° F., the company felt that they had available information on materials which would probably stand up to the stresses to be met in an aircraft propulsion unit, and they decided to collaborate with Group-Captain Whittle in the design and manufacture of a jet-propulsion engine.

In this type of engine, air is drawn into the compressor, compressed, heated in combustion chambers by the injection of fuel, partially expanded in the turbine wheel which drives the compressor, and expelled through an exhaust pipe to provide the propelling thrust by reaction. Details are not yet available for publication, but it can be said that the first propulsion unit was completed and run on test in April, 1937. Further engines were manufactured by the company incorporating various modifications which experience on the test-bed showed to be necessary. Eventually difficulties were overcome and an engine was installed in a plane built by the Gloster Aircraft Co., Ltd., and successfully flown for the first time in May, 1941. A similar engine, manufactured by the British Thomson-Houston Co., Ltd., was sent to their Associated company in the United States—the General Electric Company (of New York)—in September, 1941, after information regarding the development had been disclosed to General Arnold, of the U.S.A.A.F., in July of that year.

It will be apparent that, as Group-Captain Whittle said in his radio broadcast, the results achieved are due, in no small degree, to the close co-operation of the entire team associated with the work.

Mr. A. McArthur, 360, Farm Street, Hockley, Birmingham, has been appointed local director for Birmingham of the Electric Furnace Co., Ltd.

The Iron and Steel Institute

Annual General Meeting held in London

THIS year is the 75th anniversary of the foundation of the Iron and Steel Institute; in normal circumstances the occasion would have been celebrated in some festive manner, but, with great events impending, the annual general meeting, held on May 11, at the Offices of the Institute, did not seem a suitable time. Mr. James Henderson, retiring president, who occupied the chair at the commencement of the proceedings, referred to this anniversary, and expressed the hope that the Institute will long continue to serve its members as well as, and even better than, it has done during the last five years.

After the initial welcome to members and visitors attending this meeting, Mr. Henderson mentioned the loss of forty members by death, referred to in the Council's Report, and directed attention particularly to the loss of two members of the Council, Lord Airedale and Dr. Hatfield. "Lord Airedale joined the Institute as long ago as 1889 and had been an honorary vice-president since 1926. Dr. Hatfield was known to all who came to our meetings, and we shall greatly miss the lively part which he took in our discussions and his enthusiastic guidance of our research activities.

"This is perhaps the appropriate time to mention that a fund is being raised to found an annual Memorial Lecture to Dr. Hatfield. The University of Sheffield has agreed to act as trustee. It will be for the Lecture Committee, representing the University, this Institute and the Royal Society, the three scientific organisations with which Dr. Hatfield was most closely associated, to decide where the Lecture is to be held, but it may well prove a satisfactory arrangement to hold it alternately in Sheffield and in connection with the annual meeting of this Institute."

The Joint Research Committees have also taken action to commemorate the services which Dr. Hatfield rendered to research, and Mr. W. J. Dawson, speaking as chairman of one of the Joint Committees with which Dr. Hatfield was very closely associated, and also on behalf of Dr. Swinden, the chairman of the Heterogeneity, Corrosion and Alloy Steel Committees, said "the members of the various Research Committees felt that something ought to be done to commemorate his connection with them in a suitable manner. They decided that perhaps the best form which that could take would be a portrait which could be kept as a memento by the Iron and Steel Institute, and accordingly Mr. James Bateman, R.A., was commissioned to undertake this. He has now carried out the work, which is to be seen on the walls of the Academy. It is my duty to ask the president to accept this portrait. I am sure that it will be hung on the walls along with others of bygone famous members of the Institute."

On behalf of the Council, the chairman thanked Mr. Dawson and all subscribers. The Council propose to hang the portrait in the library.

Bessemer Gold Medal

As previously announced, the Bessemer Gold Medal for this year has been awarded to Mr. Easington Lewis, Director-General of Munitions and Aircraft Production in Australia, and a member of the Institute since 1921. Mr. Easington Lewis's outstanding services to Australia's war effort were recently acknowledged by the King, when he was made a Companion of Honour.

Report of the Retiring President

"In my presidential address two years ago," said Mr. James Henderson, "I referred to the need for intensifying the industry's research activities. You will have seen from the Press, and I am pleased to be able to confirm to you now, that the British Iron and Steel Research Association has recently been formed for this purpose. The intention is that members of the Association shall be companies who are members of the British Iron and Steel Federation and its allied associations, while there is provision for associate membership of connected industries. The Federation will nominate 22 members of the Council and the Institute 9. We wish every success to the new Research Association. Those who are responsible for its guidance know that any move to further the prosperity and well-being of our industry can count in the future, as always in the past, on the heartfelt support and assistance of this Institute.

"Considerable thought has been given by your Council and by the committee appointed by it to questions affecting the future status and well-being of metallurgists. We wish to pay tribute to the foresight of the Advisory Council of the Department of Scientific and Industrial Research in appointing a committee, of which Dr. McCance is chairman, to investigate the supply of metallurgists after the war, and we are looking forward to seeing their report on this important subject. The Council submitted a report to that committee and gave evidence, and, arising out of these investigations, authorised the publication of a paper on the training of metallurgists which has attracted a good deal of attention.

"There are other developments. Jointly with the Institution of Mining and Metallurgy and the Institute of Metals, the Council have agreed to sponsor a National Certificate in Metallurgy. This will be operated by a Committee of the three Metallurgical Institutes and the Board of Education, and we hope that it will prove a real encouragement to the many lads who attend part-time courses in technical colleges. An announcement will be made soon, and the scheme will begin to operate this autumn.

"Together with the Institute of Metals, we are studying the possibility of assisting metallurgists to attain professional status equal to that enjoyed, with such great benefit, by engineers, chemists and members of other professions. These matters will all play their part in improving the technical education and professional status of the scientists and technicians in our industry.

They form a complement to the improvement of technical education which will result from the Bill now before Parliament."

In concluding his remarks, Mr. Henderson expressed his thanks to all members of the staff for their loyal services. Special reference was made to Mr. Chattin, assistant secretary, who has done yeoman service; to Mr. Elsdon, who completes forty years' service this year —a well-deserved tribute was paid for the admirable way he has built up the library from small beginnings; Miss Davison, his assistant, who has recently completed 25 years' service, was congratulated, as was Miss Dowd, the accountant, who has also completed 25 years' service. Particular mention was made of Mr. Headlam-Morley, the secretary, who took over the duties just 10 years ago. "He threw himself wholeheartedly into the work. Especially near to his heart is the work of the Joint Research Committees. It is interesting to note that during his term of office the total membership of the Institute has increased by 45%, and, what is specially significant, the British membership has been doubled. His selection, 10 years ago, has been an outstanding success."

The New President

In introducing the new president, Mr. Henderson said the name of Dorman is almost enough. Messrs. Dorman Long and Co. are known throughout the world both for plain material and for fabricated, and, as Australia is much in the news nowadays, mention may be made of Sydney Bridge as an example of their work. Mr. Dorman's own career has been completely identified with his company, except for the period of the last war, when he served with the Green Howards. Besides being executive director of Dorman Long and Co., he is chairman of several of their associated companies, and has held in past years the presidency of the British Iron and Steel Federation, the National Federation of Employers' Organisations, the Cleveland Institute of Engineers, and others. He brings to his new office the widest knowledge of our industry and a very full experience of administrative work.

Mr. Arthur Dorman, in taking the chair, said his first duty was to propose a vote of thanks to his old friend Mr. James Henderson, which was ably seconded by Professor Thomas Turner. It is noteworthy that Mr. Henderson has been a member of the Iron and Steel Institute for 52 years, and the president announced that the Council has elected him an honorary member.

Presidential Address

The North-East Coast, owing chiefly to the discovery of the Cleveland ironstone main seam by Bolchow Vaughan and Co. in 1850, rapidly took the leading place in the manufacture of foundry and forge pig iron, and later on became one of the largest steel manufacturing districts in Great Britain. It has often been said that it is profitable to look back on the past to enable one to learn from experience useful lessons for the future, so I propose to give a short review of the development in the North-East district since the beginning of the century. The chief features have been the very large reduction in the demand for foundry pig iron, the steady development of the basic open-hearth process for the manufacture of steel, and a marked reduction in the number of blast-furnaces built, coupled with greater output per furnace and the erection of coke-ovens at the blast-furnaces. As a result of this the name "Ironmaster" has almost disappeared, together with practically all the old ironmaking firms—most of them household names—and this century has seen the gradual evolution of the large composite iron and steel works.

Although I do not intend to dwell on the distant past, I find there were in 1880 no fewer than 167 blast-furnaces on the North-East Coast capable of being put into operation, whereas in 1900 there were only 123; the average number blowing during that year was 93—about 50 on Cleveland iron and the remainder on hæmatite and special iron—the average weekly make per furnace being just over 600 tons. The output of iron of the United Kingdom in 1900 was approximately 9,000,000 tons, the North-East Coast accounting for rather more than one-third of the total. The national steel output in 1900 was 4,900,000 tons, of which only about 300,000 tons were made by the basic open-hearth process and 490,000 tons in the basic Bessemer converter, the remainder being acid steel. The world production of pig iron was just under 40,000,000 tons and that of steel just under 28,000,000 tons.

It is interesting to compare the above figures with those for 1937, the last year for which complete published records are available, and during which the whole of the country produced 8,490,000 tons of pig iron. There were only 50 blast-furnaces on the North-East Coast, and the average number blowing during the year was 34; the total make of iron for the district was 2,429,000 tons, and the average weekly make per furnace had risen to 1,400 tons. This is a very small output compared with that of the large blast-furnaces in the United States of America and other parts of the world, but undoubtedly the use of a large proportion of lean local ironstone, coupled with the long-established practice of calcining it in kilns adjacent to the furnace, has retarded the development of large blast-furnaces in this district.

The year 1937 saw the record make of steel ingots for the country to that date, the total being just under 13,000,000 tons, of which no fewer than 9,660,000 tons were produced by the basic open-hearth process. The production of basic Bessemer steel ingots over the year was 417,000 tons, but no steel had been produced by this process between 1924 and 1934. You will therefore see that 74% of the total ingots were made by the basic open-hearth process, as against 6% made by this process in 1900. The world production of pig iron in 1937 was 102,000,000 tons and that of steel was 133,000,000 tons, so that the steel production of the world has definitely overtaken the iron production.

My object in quoting these figures is to show the large increase in the output of steel since the beginning of the century, especially by the basic open-hearth process, the small but steady decline in the production of iron in this country and the quite considerable reduction in the number of blast-furnaces in operation coupled with larger makes.

You will realise that it was not very easy to base large composite iron and steel works on the old blast-furnace plants. Our grandfathers were great pioneers and took full advantage of the cheap fuel, cheap local ironstone and the large demand for pig iron which existed in those days. Blast-furnaces were scattered up and down the country, in several parts of the County Durham and even in the Esk Valley near Whitby. Steel was still in its infancy. Although the British steel output had risen from about 2,000,000 tons a year in the early 'eighties, it was still short of 5,000,000 tons in 1900. Men such

as my father, Sir Arthur Dorman, who showed great determination in encouraging the use of molten Cleveland iron in the manufacture of basic open-hearth steel, Mr. Benjamin Talbot, the inventor of the well-known process which bears his name, and Sir Hugh Bell—the last two being past-presidents of this Institute—saw clearly the necessity for the installation of large composite iron and steel works equipped with coke-ovens so as to get the full benefit of both coke-oven and blast-furnace gases in the steelworks.

Considerable progress was made in the first fourteen years of the century, but times were hard, competition from abroad was severe, and the cost of new plant and machinery was considerably greater than was necessary a generation earlier. The first world war found our industry inadequately equipped for the demands made on it, and as a consequence large schemes were undertaken during the war to meet the situation by building complete new steelworks. The financial arrangements which permitted these new works to be built were not generous, and, as some of the schemes were not completed till long after hostilities had ceased, several firms were left with unbalanced plants.

I do not propose to dwell on the post-war depression which fell in all its severity on our trade, but in 1933 the horizon cleared, orders became more plentiful and prospects more stable. As a result a number of blast-furnaces were modernised, new coke-ovens built and many improvements made in steel furnaces and rolling mills. In 1939 it is true to say that many of the steel furnace plants and rolling mills compared favourably with the best practice in any country, and, although there were still too many small blast-furnaces operating on the North-East Coast and in the country generally, a definite start had been made towards modernisation ; in most cases modern coke-ovens were operating alongside the blast-furnaces and full advantage was taken of the coke-oven and blast-furnace gases.

When one turns to the future several interesting questions arise, in all of which scientific research will play an important part. It seems certain that there will be an increased cost of fuel as a permanent feature operating in the future. To work the large modern blast-furnace satisfactorily careful preparation of all materials used is necessary, and beneficiation of the iron ores, especially those of the leaner kind, becomes increasingly important and economic the higher the level of coke prices. No doubt a great deal has been done, but it seems that attention might be given to the possibility of applying some form of magnetic roasting to certain of our lean home ores, to be followed by crushing, magnetic separation and finally sintering or agglomeration to a form suitable physically for large fast-driving furnaces.

It seems that such investigation is required, because all the home ores available in bulk are on the lean side and likely to get leaner. With both railway transport and fuel likely to show much higher costs and with large quantities of lean home ores available I think the position would quickly become clear that a good deal of money could be expended in experiments upon the general lines suggested, and, looking far ahead, the future of the iron trade in this country may hinge on whether such a result can be achieved or not at a reasonable cost. In any case, considerable quantities of foreign ores will be necessary if the present outputs are to be maintained or increased. It is generally accepted that attainment of optimum results in large modern furnaces demands a comprehensive scheme of crushing, grading and sintering of ores, and the charging of all ingoing materials according to size.

Another point which merits more scientific investigation than has been given to it in Britain is the consideration whether some benefits may not arise from enriching the air blown into the blast-furnace with a certain limited amount of oxygen. Although the cost of oxygen has in the past been very high, the probable development and extended use of synthetic products requiring nitrogen may enable this cost to fall to economic levels. The idea of using a limited amount of oxygen in the ordinary air blown has always been attractive, because by a slight variation in the amount added the blast-furnace operator would have better control of the quality of the products and secure more regular working. . . .

The future of the steel furnace is a very interesting question. Will the basic Bessemer process come back again into general favour ? Modern supporters maintain that the exclusion of basic Bessemer steel from most British Standard Specifications arose from its unreliability during the early days of the process and that engineers are prejudiced in refusing to recognise improvements which have been made in recent installations. . . .

With iron and steel being made in many new countries during the last 10 or 20 years, I feel very strongly that it is essential that the finishing trades of this country should have as a base a highly efficient heavy iron and steel industry capable of producing an adequate output of iron and steel under most modern conditions. We must regain and expand our export trade, which will only be possible if all sections of the industry are equipped to meet world competition. I consider that there is no reason why the 1937 output of steel should not be exceeded. This will necessitate a great deal of reconstruction, as the war conditions which have now lasted nearly five years have of necessity deferred many schemes of modernisation. It is important that a commencement of this work be made at the earliest possible moment, and also that immediate steps be taken to overtake the arrears of repairs and maintenance which inevitably have accumulated through working at high pressure during the period of the war.

A very interesting review of the Joint Research Committees of the Iron and Steel Institute and the British Iron and Steel Federation* has recently been published, which shows clearly the excellent work that has been done for a number of years. Sir William Larke, the chairman of the Iron and Steel Industrial Research Council, has been largely instrumental in centralising the efforts of the trade, and our thanks are due to him. . . .

In expressing thanks to the president for his address, Sir William Larke, K.B.E., said he felt that a presidential address should reflect just sufficiently on the past to give the benefit of its lessons in dealing with the present and to indicate the path which should be followed in the future. Mr. Dorman's address complies with this specification. He regarded it as unfortunate that tradition prevents a discussion of an address of this kind, because it contains so much matter calculated to provoke a very interesting discussion, but he permitted himself to make two comments—relating to the use of native ores and the question of export trade.

*The Iron and Steel Institute, 1943, Special Report No. 29.

Technical Sessions

TWO papers were presented for discussion in the morning session and several in the afternoon session, the latter including five papers concerned with the temperature measurement of hot metals, particularly liquid steel. The two papers at the morning session were presented for joint discussion, as were several in the afternoon session. Here it is only possible to refer briefly to the papers.

The Heating of Open-Hearth Furnaces with Mixed Coke-Oven and Blast-Furnace Gas.

By R. W. Evans, B.Met.

IN this paper the author discusses the theory and practice of mixed gas operation as a result of 20 months' experience of mixed gases in a plant, during which a change-over from 100% producer gas to 100% mixed-gas was effected. Provided that the blast-furnace gas can be efficiently and economically used elsewhere, the author is of the opinion that the best method of firing open-hearth furnaces is to use cold coke-oven gas and tar, tar-oil or pitch, particularly where the very high metallurgical loads, which have to be carried, require tilting rather than fixed furnaces, and where the coke-oven gas is likely to be lean. The author discusses the principles of flame development, the role of the flame; slag foams, their reaction on furnace output and wear; the development of luminosity in coke-oven and blast-furnace gas flames; furnace design; and some metallurgical aspects resulting from the use of mixed gas. A rather full abstract of this paper was published in our January, 1944, issue.

The Study of the Thermal Performance of Open-Hearth Furnaces by the Correlating of Operating Data

By A. H. Leckie, Ph.D., F.I.C.

(*British Iron and Steel Federation*).

THE investigation of open-hearth furnace performance is always complicated by the large number of variables involved, many of which cannot be assessed in any quantitative way. Statistical methods, which have proved so successful in other fields of work, such as agriculture and biometry, where large numbers of irregular variables are encountered, are therefore particularly applicable to the study of open-hearth problems. Such work, however, has chiefly consisted of the listing of a large amount of useful and comprehensive data on open-hearth practice and the preparation of graphical relationships, without any development of more elaborate statistical examination.

In the present paper a method is described by which much useful information on the effect of certain variables on the thermal performance of open hearth furnaces may be determined from ordinary works records. It is assumed that the furnace is fitted with pyrometers which permit the gas and air preheat to be assessed. The only other essential instrument is a meter for measuring the fuel input to each individual furnace; whilst many furnaces in Britain are still without this, such installations are rapidly coming into use, and it is practically impossible to conduct serious investigations on furnace efficiency without a precise knowledge of the fuel input to individual furnaces.

The work is presented in two sections, in Section I the author shows how the appropriate correlation methods may be used to determine the optimum gas rate and air/gas ratio, and to investigate the effect of many variables in a quantitative way and the changes in thermal efficiency under various conditions. The methods are illustrated by examples taken from actual practice. Section II is devoted to the discussion of simple methods of measuring and calculating the quantities involved.

Survey of Liquid Steel Temperatures in Basic Open-Hearth Furnaces

By D. Manterfield.

A TEMPERATURE survey of the larger type of basic open-hearth furnaces is reported in this paper. In the first part, details are given of the type of furnace and slag dealt with in the survey. The second part concerns the temperature fluctuations during the progress of a heat. The uniformity of temperature in the bath is shown to be governed by its activity. This report is given in an abridged form in our January, 1944, issue.

Barrier-Layer Photo-Electric Cells for Temperature Measurement

By T. Land, M.A.

Research Department, Messrs. William Jessop and Sons, Ltd.

THE measurement and control of high temperatures is of considerable practical importance in steel-making, and notable advances in the technique of measurement have been made in recent years. The measurement of liquid steel temperatures in the melting furnace has received particular attention, and a satisfactory solution of the problem has been reached. The measurement of the temperature of the liquid steel in the foundry is at a less advanced stage of development, and it was considered that the barrier-layer photo-electric cell might provide a useful means of measuring such temperatures under foundry conditions.

The measurement of temperatures in the foundry has usually been carried out with disappearing-filament optical pyrometers. These have given good service, but are not beyond criticism. The chief alternative would be the total-radiation pyrometer, but this also has its limitations under foundry conditions. It can be stated, however, that an instrument combining the sensitivity of the optical pyrometer with the direct reading given by the total radiation pyrometer would be most welcome. The photo-electric cell offers this combination, and has the additional merit of very rapid response. Cells of British manufacture are now available which are claimed to be superior in sensitivity and stability to any previously manufactured commercially, and preliminary tests showed that the cells were very reliable. An investigation has, therefore, been made of the suitability of this type of cell for temperature measurement.

Photo-Electric Cells

There are two distinct types of photo-electric cells. The vacuum and gas-filled cells are in appearance not unlike a radio valve and operate on the principle of the photo-electric emission from surfaces sensitised by caesium, potassium or other photo-sensitive elements.

The current from such a cell is very small, and must be amplified before it can be used to operate an indicator or recorder; furthermore, the cell requires an external source of potential for its operation, and the current obtained depends, in some cases rather critically, upon the voltage applied.

The barrier-layer type of cell, with which this investigation is concerned, is of totally different construction, and is probably most widely known from its use in photographic exposure meters. It consists of a small disc, usually of iron, upon which is laid a thin layer of selenium, which is further covered by a transparent metallic film. The cells used in the present investigation were about the size of a halfpenny. The barrier-layer cell generates its own current, requiring no externally applied voltage, and a current large enough to operate an indicator or recorder can readily be obtained. Selenium barrier-layer cells have in the past shown certain unfortunate features which have made the more careful investigators rightly cautious in using them for precision measurements. The cells tested in the present series of experiments proved adequately reliable for the purpose in view.

Scope of the Present Investigation

The disappearing-filament pyrometer can be calibrated by reference to the laws of radiation. It is shown in Part I of this paper that the photo-electric cell can be calibrated in a similar way. It is only necessary to know the spectral distribution of sensitivity of the cell and its deviation from linear response to illumination intensity in order to calculate the ratio of the currents generated when the pyrometer is sighted on objects at different temperatures. A black-body furnace is not a convenient source of radiation, and it is shown that a tungsten ribbon-filament lamp can be used as a secondary standard of temperature for the calibration of cells.

In Part II of the paper is given an account of the experimental work done on the general properties and the calibration of the photo-electric cells. For normal industrial practice an accuracy of ± 5° C. (± 9° F.) is adequate, and there are many cases on which an uncertainty of ± 10° C. (± 18° F.) is not serious. With this consideration in mind, no attempt has been made to calibrate the cells to an accuracy of better than ± 3° C. (± 5° F.). To obtain a further degree of precision would entail a great elaboration of the experimental technique, which was not thought to be necessary. It has, however, been possible to provide a standard of illumination of high precision, and measurements of the fatigue and other general properties of the cells have been made to an accuracy of about one part in a thousand.

The results of the calibration are given in the form of tables in Appendix I, while details of some of the experimental results are given in Appendix II.

Conclusions

The experimental results obtained show that the cells tested are quite suitable for the industrial measurement of high temperatures. Care must be taken with fatigue and temperature coefficients. The response of a cell declines by an amount which, under adverse conditions, may correspond to as much as 10° at 1,700° C. (18° at 3,100° F.). At least half of the change occurs during the first minute, and after an hour's illumination the response is very steady. The normal seasonal variation of atmospheric temperature in Great Britain may be taken as about 25° C. (45° F.). With some cells this may cause changes of ± 5° C. (± 9° F.) in the calibration. The error from this source can usually be reduced by including a suitable resistance in the measuring circuit; but care must be taken that the resistance is not large enough to alter the calibration of the cell.

The relative cell currents for different temperatures of the hot source seem to be very nearly the same for all the cells. A standard table (Table VIIIA, Appendix I) represents the calibrations of the cells within limits which rarely exceed 2° C. (4° F.) over the temperature range 1,350°–1,750° C. (2,460°–3,180° F.). An extended source of black-body radiation is rarely available, but a tungsten ribbon-filament lamp may be used to calibrate the cells, provided that allowance is made for the difference in effective wave-length between the cell and the optical pyrometer used to calibrate the lamp. When the cell is calibrated in this way it may be necessary to use a different optical system for calibration from that employed in the pyrometer. The calculation of the effect of changing the optical system rests on certain simple geometric relations, and experiment shows that it should not involve an error of more than a few degrees.

A Thermocouple Method of Measurement of Liquid Steel Casting-Stream Temperatures

By D. A. OLIVER and T. LAND.

THIS paper describes a simple and successful method which has been devised for measuring the temperature of the casting stream in the foundry. It can be applied to castings of more than 5 cwt. in weight with only slight modification of standard foundry practice. It appears essential to employ some type of high-speed temperature recorder in view of the short time available for the measurement. The method appears to be suitable for the investigation of emissivities and the ladle cooling of liquid steels under foundry conditions. The authors' description of this method is reproduced in our last issue.

The Emissivity Characteristics of Hot Metals with Special Reference to the Infra-Red

By D. J. PRICE, B.Sc., A.Inst.P., and H. LOWERY, D.Sc., F.Inst.P.

(*South-West Essex Technical College.*)

THE investigation of the spectral energy radiated by solid and liquid metals at high temperatures is of double interest: First, the measurement of radiation in both the visible and infra-red portions of the spectrum seems to be the simplest method for determining high temperatures, provided that the relation between the intensity of the emitted radiation and the temperature of the hot body is known; secondly, recent developments in physics have revealed the fundamental character of the relation between the emission of energy by matter and the corresponding atomic processes.

In the theory of temperature radiation the hot body is assumed to be of such a nature that it would absorb all radiation incident on it, whatever the nature of this radiation might be. Such a radiator, termed "a perfect black body," is rarely met with in practical pyrometry. This is a well-known fact so far as measurements of steel ingots, molten metals in crucibles and

the like are concerned, but it is necessary to draw attention to the fact that even the radiation of closed furnaces, such as the open-hearth furnace, is not a perfectly "black body."

Deviations from black-body radiation are known to become more noticeable with long wave-lengths of radiation. Besides these, allowance must be made for the absorption of radiation by water vapour, carbon dioxide and furnace gases and vapours. Difficulties increase if hot metals outside the furnace are considered. Here the surrounding temperature is low relative to that of the body, and consequently absorption and reflection of radiation by the hot body can usually be neglected. We can then speak of the radiative properties of the metal, or, rather, of the metal surface, since, except for transparent materials such as molten glasses, emissivity is essentially a surface phenomenon. Since most hot metals have surface films, oxide layers, etc., the constitution of the surface and therefore the quantity and quality of the radiation emitted are capable of great variation.

Definition of Emissivity

Much confusion is caused by the various definitions and uses of the term "emissivity" that have been employed by various writers. Some use the word to signify the amount of energy in ergs radiated by each square centimetre of surface per second either normally or integrated over the whole hemisphere.

This definition is of little value unless accompanied by a very precise temperature value, since the actual energy radiated varies as a somewhat higher power of the temperature of the hot body. As it is not often possible to ascertain the temperature to a high enough degree of precision, or even to maintain it sufficiently constant for the period of time involved in the making of the measurements, some alternative should be found. This is readily presented in the form of a comparison with a black body under the same conditions, and leads to the following definition of emissivity, which is certainly of greater use and significance :—

> In the amount of energy radiated per second per unit area by a perfect black body at a specified temperature over an infinitesimally small wave-length range be taken as unity, then the amount of energy radiated in a specific direction under the same conditions by any other body is known as the emissivity of the body.

From this definition it will be seen that the emissivity of any specified surface is a function of three variables—viz., temperature, wave-length, and angle of emission. If this function is integrated over the whole wave-length range the "total emissivity" can be found. This term has been used by many writers to indicate the emissivity found by means of the so-called total radiation pyrometer. It should, however, be pointed out that it is highly improbable that the pyrometer is uniformly sensitive over the complete wave-length range, and therefore some correction may be necessary to allow for the characteristics of the instrument.

In the present paper the term emissivity is used as already defined. In addition to the discussion of theoretical and practical considerations in connection with emissivity, the authors critically survey the relevant literature. The application of emissivity data to the correction of pyrometer readings has been examined, and the necessity of an adequate knowledge of emissivity data is indicated. The information at present available does not meet this need, especially in the important case of iron, and, in view of this, suggestions for future experimental researches are noted.

Correlation of all available data appears to indicate a zero temperature coefficient of emissivity (for all substances) at a specific wave-length in the infra-red region. This implies that at a certain wave-length peculiar to each substance the emissivity correction to a pyrometer would take a simpler form than at present.

The authors conclude that, due to the paucity of data at present available, a complete investigation of the emissivity of iron and other metals is needed. Not only should spectral emissivity be measured over a wide range of temperature, but care should be taken to investigate the variation of emissivity with angle, state of surface and purity of specimen. Experiments on these lines are now being carried out by the present authors, under the auspices of the Foundry Steel Temperature Sub-Committee of the Steel Castings Research Committee.

The Drift of Selenium Photo-Electric Cells in relation to their use in Temperature Measurements

By J. A. HALL, A.R.C.S., B.Sc., D.I.C.
(*The National Physical Laboratory*).

THIS paper describes experiments carried out in order to study the effect of "drift" in selenium photo-electric cells, and forms part of an investigation to determine the suitability of these cells for use in high-temperature measurement. For this purpose the phenomenon of drift assumes a position of importance ; the effect shows itself as a change (normally a diminution) in the current given by the cell under prolonged exposure to light, and its magnitude in most of the nine cells available for experiment was such as to make an accurate calibration impossible, except under closely prescribed conditions. It was found that the drift of seven of the nine cells examined, for instance, was too great to permit their use for the most accurate work. However, a comparison with work done by Land, on "Barrier-Layer Photo-Electric Cells for Temperature Measurement," previously referred to, showed that his cells were, on the average, more satisfactory, and that, by pooling the two batches, eleven satisfactory cells could be obtained from a total of nineteen.

The following characteristics of the drift effect were noted. The drift expressed as a percentage is independent of the current given by the cell, and hence of the brightness to which the cell is exposed. If a cell is allowed to drift by exposure to radiation from a source at a given temperature and the temperature is then increased, the initial response to the higher temperature is almost, but not quite, as great as if the cell had not previously drifted at the lower temperature. Drift is much reduced when deep-red and infra-red radiation is excluded. Among the filters examined, a $\frac{1}{4}$ in. thickness of Calorex glass was sufficient to obtain the maximum observed reduction in drift (about 50%). No drift was observed when the cell was exposed on open circuit. If the illumination of a cell is interrupted for a short period and then resumed, the sensitivity of the cell recovers somewhat during the "rest" period, but rapidly resumes the value it had just before, irrespective of whether it had previously been allowed

to drift for a long or a short period. The speed of recovery depended to some extent on the circuit conditions under which the cell was allowed to recover, and was somewhat rapid when the cell was short-circuited.

Taken in conjunction with the work of Land, the results of the experiments described by the author show that if barrier-layer photo-cells are to be used for precise temperature measurement it will be necessary for them to be carefully selected. It appears that the best precision would be attained by calibrating the cells after exposure for a considerable time to the maximum intensity that they would experience in the pyrometer and to use them as far as possible under similar conditions. Since the cells soon returned to their "drifted" condition on re-exposure after periods of darkness of half an hour or so, the period of exposure used in making the temperature measurement need not be long. It is probable, however, that the errors caused by drift in suitably selected cells would be small compared with those from other sources, and precautions of this kind would then be of little value.

A Study of a Shell-Steel Ingot

By D. BINNIE, Ph.D.

(*The Lancashire Steel Corporation, Ltd.*)

AT the request of the Committee on the Heterogeneity of Steel Ingots, an ingot of shell steel has been examined and the information obtained is the subject of this paper. The ingot was teemed uphill and contained 0·47% carbon and 0·88% manganese. It was made by the basic open-hearth process and the steel-making and teeming data are tabulated. The ingot was selected from the second plate of four ingots; it was cut, planed and polished to expose the section through the vertical axis. The sulphur print and analyses at the standard positions of the Committee on the Heterogeneity of Steel Ingots are shown.

Longitudinal sections were cut from the feeder head and from the base of the ingot, and transverse sections from the top, middle and bottom of the ingot proper, all of which were subjected to close examination.

Among features brought to light is the presence of white spots of precipitated ferrite, seen in all sections of the ingot except the feeder head. The intensity and distribution of these white spots are considered. The lower half of the ingot had, on sulphur printing, a zoned effect: A light-coloured zone at the surface, a dark zone, a light coloured zone, and again the normal dark zone of the ingot. This zoning is compared with the acid-etched surface of the metal. A detailed analysis of the steel throughout the zoning is also given.

The Examination of a Rimming-Steel Ingot containing 0.29% of Carbon

By T. SWINDEN, D.Met.

(*Central Research Department, the United Steel Companies, Ltd.*)

IT has been repeatedly suggested that the occurrence of a relatively pure rim zone in low-carbon rimming steel may be due to the primary precipitation of iron in the δ-form. The hypothesis has never been elaborated, but presumably it might be suggested that the mechanism of solidification would be somewhat along the following lines:—

The carbon monoxide evolution on the advancing rim wall, resulting from the carbon and oxygen reaction during effervescence, continuously sweeps away the mother-liquor (which is being gradually enriched in carbon and oxygen), thereby acting as a barrier between precipitated δ-iron and the mother-liquor. The peritectic transformation—i.e., the reaction between δ-iron and mother-liquor—is thereby suppressed, and the rim solidifies with a lower content of carbon—and other constituents—than when solidification occurs in the quiescent manner of killed solid steels. Since most commercial rimming steels are cast from a liquid metal having a carbon content below about 0·2%, the formation of a rim zone with a carbon content of approximately 0·1%, which is the limit for δ-iron according to Adcock's diagram, affords a basis for this hypothesis.

One difficulty in accepting this theory, in the author's mind, has always been the profound effect of a small addition of silicon or aluminium, which, as is well known, is capable of completely suppressing the rimming action. It is difficult to fit this fact into the δ-iron theory.

However, the question arose again in the Ingots Committee as to what the carbon content would be if a steel containing considerably over 0·2% of carbon was produced as a rimming quality. Mr. James Mitchell, of Messrs. Stewarts and Lloyds, Ltd., kindly undertook to provide a typical ingot of this grade, and the present note is the result of a joint examination with Mr. Mitchell, to whom the author tenders his best thanks for most helpful collaboration, of a basic Bessemer ingot, of which the pit sample contained 0·29% of carbon. A typical analysis would be:—

Manganese.	Silicon.	Sulphur.	Phosphorus.
0·4% ..	Trace ..	0·025% ..	0·025%

The selected ingot was approximately 20 in. square and weighed 2½ tons.

Certain striking differences in the rimming process are noted between this type of material and low-carbon rimming steel. The effervescence itself is more akin to an ebullition similar to the "boil" of a bath of steel in the furnace; in other words, the gas evolution is in relatively large bubbles from a relatively small number of points per unit volume, as compared with the indefinitely large number of small bubbles that one gets during the effervescence of low-carbon steel. Another point is that this type of steel invariably produces a thick viscous scum on the top of the ingot during effervescence instead of the usual fluid slag which rises in low-carbon basic Bessemer material. It is also almost invariably found necessary to plate these ingots towards the end of the so-called effervescence to avoid final eruption which gives a volcano top.

It is seen from the report that the sharp demarcation between the rim and core, common to low-carbon rimming steels, is replaced in this case by an indeterminate zone of approximately 1 in. depth, but nevertheless the heterogeneity of this ingot is of the same general character as that of a low-carbon rimming steel.

The macroscopic etching of the ingot reveals the presence of three zones:—

(1) An outer chilled zone, approximately ¼in. in width, of small crystals.

(2) A zone, 1¾ in. in width, of columnar crystals, containing also a number of small lenticular-shaped blow-holes.

(3) An inner zone of equi-axed crystals, 8 in. in width, showing at the indeterminate zone coarse crystals which were markedly refined towards the centre of the ingot.

Chemical Examination.—The carbon and oxygen analyses show a composition variation different in some characteristics from that of a normal rimming steel. The outer edge of the ingot has the very low carbon content of 0·14$_5$% that increases rapidly to 0·25%, which is the average figure over the major part of the rim zone. The indeterminate zone shows a minor peak at 0·30$_5$% of carbon, after which the carbon curve increases to a maximum of 0·36% in the core at 5¼ in. from the outer edge. The bulk of the core zone averages 0·31–0·32% of carbon, decreasing towards the centre to 0·28% of carbon. The oxygen contents are decidedly lower than in a rimming steel of lower carbon content.

Summary and Observations.—This ingot of 0·29% carbon steel has several features which differ from those of a normal low-carbon rimming-steel ingot, such as the unusual appearance of the rimming action, the presence of columnar crystals and the variation in carbon content. It does, however, provide a definite answer to the question as to whether the iron in the rim portion has been deposited as δ-iron. It is shown that the rim contains essentially about 0·25% of carbon, and it is submitted that this could not have been deposited in the form of primary crystals of δ-iron.

No satisfactory explanation can be submitted for the occurrence of lower carbon contents (below 0·2%) in the outer skin of this ingot to a depth of about ¼ in. Mr. Mitchell has subsequently communicated a further note on this latter point. Three further casts were selected containing respectively 0·28%, 0·32% and 0·31% of carbon, and one ingot of each was drilled at eleven positions, ¼ in. deep, with a ½-in. drill, at the mid-point of the ingot length. In each case the carbon contents were confirmatory of those obtained in the outer skin of the ingot reported upon in the paper.

British Non-Ferrous Smelters' Association

In conformity with present trends, in which sections of industry are forming associations to look after common interests, the British smelters of the primary ores of aluminium, antimony, magnesium, tin, zinc and the precious metals have formed an Association. The object of this Association is "The consideration and furtherance of the common interests in the maintenance and development of the non-ferrous smelting industry in Britain. The following companies are members of the Association :—The British Aluminium Co., Ltd. ; British Tin Smelting Co., Ltd. ; Copper Pass and Son, Ltd. ; Consolidated Tin Smelters, Ltd. ; Goodlass Wall and Lead Industries, Ltd. ; Imperial Smelting Corporation, Ltd. ; Johnson, Matthey and Co., Ltd. ; Magnesium Elektron, Ltd. ; and South Wales Aluminium Co., Ltd.

Mr. Cecil Kimber, director of Specialloid, Ltd., has recovered from his illness, and his many friends will be pleased to learn he has returned to duty. A virulent bacillus in the back teeth caused the trouble that has kept him away from business since last August.

Metals in the Stars

THE Astronomer Royal, Sir Harold Spencer Jones, F.R.S., delivered the 34th annual May Lecture of the Institute of Metals, on May 17, in the Hall of the Institution of Mechanical Engineers, London. Dr. W. T. Griffiths, president of the Institute of Metals, was in the chair. A brief summary of the lecture on the above subject is given in the following notes :—

The radiations absorbed or given out by the atoms of a given element are determined by the different possible energy levels of the atoms of that element. The ultimate lines are those associated with atomic transitions from or to the unexcited or ground-state and provide the most sensitive test for the presence of any particular element. The spectroscopic tests for the presence of the metals in the stars are generally more sensitive than those for the non-metals because the ultimate lines for the metals are generally in the accessible region of the spectrum. When the energy supply is sufficiently great, the outermost electron may be entirely removed from the atom ; the atom is then said to be ionised and gives a different spectrum from that given by the neutral atom. Successively higher stages of ionisation can be produced by driving off two or more of the outer electrons.

The features of the sun and stars that can be studied spectroscopically are merely superficial. The elements present in the outer layers of the sun are essentially the same as those found in the earth. The relative abundance of the metals in the sun, in the earth and in meteorites are generally about the same. There are some striking differences in the case of the non-metals ; thus, for instance, the sun consists predominantly of hydrogen and helium. This leads to some interesting conclusions about the evolution of the atmosphere of the earth.

The stars show a wide diversity in spectra, but it is possible to arrange the spectra in a continuous linear sequence. The differences in stellar spectra are due primarily to differences in temperature and not to any marked differences in the relative abundance of the various elements. Density, however, has some effect, and from the detailed study of the spectra of giant and dwarf stars of the same spectral type it is possible to infer the luminosities and therefore the distances of the stars.

The spectrum of the sun's corona, which until recently provided one of the unsolved problems of astronomy, has recently been shown to be due to atoms of iron, nickel and calcium in states of very high ionisation. Interstellar space contains an extremely tenuous gas, in which atoms of the metals calcium, sodium, titanium and iron have been detected.

The H and K lines of ionised calcium are very intense in the spectrum of the average star and can be identified in the spectra of distant universes. This makes it possible to determine the line-of-sight velocities of these universes and, through the correlation between distance and line-of-sight velocity, to infer their distances.

Mr. J. S. Whitmore, M.T.S.Inst., late chief engineer of Messrs. John Lysaght, Ltd., has been appointed representative in Wales for Messrs. W. H. A. Robertson and Co., Ltd., of Bedford. His address is "Bermuda," Glasllwch, Newport, Mon.

MICROCHEMISTRY
APPARATUS · METALLURGICAL APPLICATIONS · TECHNIQUE

IF we wished to write a modern fable entitled "The Progress of Microchemistry," it would run something like this: More than a year ago, a well-known Microchemist invited views on the formation of a new Microchemical Society, and received much encouragement and approbation. Hearing, however, that a National Society was then negotiating to assimilate the former Microchemical Club, he refrained from any action which might prejudice this. Some months passed, and, as negotiations were apparently still in progress, a public meeting appointed a representative committee which was to try to improve the position of organised Microchemistry in this country. The representative committee, being assured that everything possible was being done, likewise held its hand, in order to avoid schisms and controversy. A month later the National Society agreed to form groups if requested to do so by a sufficient number of its members. Five months slipped past. The members of the National Society were then informed that a Microchemical Group was being formed, and it was hoped that all members who wished to join it would intimate their desire "within a fortnight." Now it is whispered by the little birds that, owing to the difficulties of travel, further developments are not likely to take place till October. Moral: "Haste trips up its own heels." We could leave this tale without further comment. We could, on the other hand, express ourselves with some stringency on it. We will content ourselves with pointing out that other societies have not found postal ballots difficult to organise, that they are the fairest way of ascertaining the desire of a national body, and that meanwhile we microchemists wait.

Organic Reagents in Quantitative Metallurgical Micro-Analysis—Part II

By R. Belcher and C. E. Spooner

In the first section of this paper some of the theoretical principles underlying the application of organic reagents to inorganic analysis were discussed briefly. In this second section we propose to deal, also briefly, with some of their practical applications to the micro analysis of metals. This does not purport to be a complete review of all applications in this field during the last decade—such a survey would be impossible in an article of this type—but it indicates some of the more important methods which have been evolved, and discusses possible applications of recent investigations. Methods for the micro determination of silver lead, copper, antimony, tin, aluminium, iron, nickel, zinc and magnesium are reviewed together with brief reference to other metals and special techniques.

GENERALLY, when an organic reagent has been applied in a metallurgical estimation, the final determination can be completed in one of four ways:—

(1) The precipitated complex can be ignited to the oxide.
(2) The complex can be dried and weighed as such.
(3) A titrimetric procedure can be applied in some form or other.
(4) The metal complex can be obtained by suitable modification of the organic structure as a highly coloured soluble derivative and determined absorptiometrically.

The titrimetric and absorptiometric methods of finishing may sometimes be used advantageously for small amounts where the weighing error would be too large, but in many cases the practical details still require developing.

When the gravimetric finish is applied to a determination it is always preferable to weigh the metal complex itself because of the necessity of having as favourable a conversion factor as possible in micro-analysis. This is not always practicable because of the doubtful composition of some of the dried metal complexes and therefore ignition to the metal oxide cannot be avoided. Thus, although α-nitroso β-naphthol was the first organic reagent to be recommended it is only during recent years that the conditions for obtaining a pure metal complex have been worked out, and ignition had to be resorted to even though this was not altogether satisfactory since different oxides were obtained unless the conditions were strictly controlled. The procedure adopted for these gravimetric determinations is generally the standard micro technique, using either the Emich filter beaker, the Pregl filter tube, or the Emich filter stick. The latter technique usually offers the best advantages.

Silver

Silver can be determined either titrimetrically, gravimetrically, or colorimetrically with organic reagents, one of the most important being diphenylthiocarbazone, usually called dithizon, which was introduced by Hellmut Fischer.[1] Silver can be determined titrimetrically with this reagent in lead, mercury, zinc, copper, cadmium, bismuth or gold, all of which, with the exception of gold, form inner complex compounds with dithizon. The structures of the gold and silver complexes are uncertain, but they are thought not to be inner complex compounds because of their insolubility in organic solvents. The separation from these metals depends on either the suppression of the interference by acid addition or because the other metal cannot react with the dithizon until all the silver has reacted. Amounts of silver ranging from 0·00001% to 0·01% can be determined in lead, and 0·001% in zinc. With copper the range is 0·1% to 1·0%, but smaller amounts can be determined by preventing the copper dithizonate interfering by means of potassium thiocyanate. Similarly, 6–100 microgram of silver in 100 mg. of mercury can be determined if potassium thiocyanate is added to a weakly acid solution. In the case of gold, 12–100 microgram can be determined in 10 mg. of gold with sufficient accuracy.

Silver can be determined colorimetrically by means of *p*-dimethylaminobenzalrhodanine with which it forms a red inner complex compound. It is used in amyl alcohol and added to the test solution made acid with acetic acid, when the complex collects at the interface of the two liquids from which it is obtained and dispersed with glycerol and ethyl alcohol. This reagent is more sensitive than the formation of silver iodide because of the colour, and large molecular weight of the organic complex. Recently[2] a new reagent 2-thio-5-keto-4-carbethoxy-1, 3-dihydro pyrimidine has been recommended for the colorimetric determination of silver. It has advantages over *p*-dimethylaminobenzalrhodanine as regards stability and in giving less intense colours with gold and palladium, whilst its sensitivity is the same. The only interference likely from a number of other ions is where they may be present in such concentration as to give a colour from the ion itself.

Finally, silver may be determined gravimetrically by the use of propylenediamine[3] which forms penetration compounds with copper, and this complex reacts with the complex anion AgI_2 to form analogous penetration complexes. The silver complex is filtered on a Pregl filter tube, washed with alcohol and ether and dried in a vacuum desiccator before weighing. The high sensitivity of the reagent and the favourable conversion factor (the complex containing 23·07% of silver) make the procedure suitable for micro-analytical practice.

Lead

Lead can be determined on the micro scale by the use of picrolonic acid, with which it forms a normal insoluble salt. The solution must be cooled to 0° C. to ensure complete precipitation, and the precipitate is weighed as the lead complex which has a good conversion factor and contains 27·25% of lead. To assist in separating lead from other metals prior to its determination as the picrolonate thiourea may be used, since this forms a penetration compound with lead nitrate which is insoluble in cold acid solution, whereas other metal thiourea complexes are soluble. The metal complex itself cannot be weighed because free thiourea is precipitated on cooling to 0° C., which is a necessary operation in the separation of the lead. We have found this method fails, however, to separate lead in lead-bearing steels.

Lead can also be determined by the use of 5, 7-dibromo-8-hydroxyquinoline[4] in solutions which are made slightly alkaline with ammonia, following which tartaric acid is added. The complex itself is weighed and contains 25·55% of lead.

Copper

A number of organic reagents are available for the micro determination of copper.

Recently,[5] a new method has been developed for the rapid colorimetric estimation of copper in steels and solders, using dithizon with which copper forms a coloured inner complex compound. Interference from all metallic ions except platinum, palladium, gold, silver, mercury, bismuth and stannous tin is eliminated by extracting the copper as the dithizonate complex with carbon tetrachloride from an aqueous solution at pH 2·3. The reaction products of silver, gold, mercury, bismuth and stannous tin with dithizon are destroyed by shaking the extract with acidic potassium iodide solution. Recoveries of better than ± 0·3 microgram were reported with this method.

The colorimetric method of Haywood and Wood[6] for the determination of copper in steel and other ferrous materials using sodium diethyldithiocarbamate appears to be suitable for application to the micro scale, since only a small fraction of the final solution is used. Nickel, when present, has to be separated by dimethylglyoxime and therefore it would be advisable to adopt the well-known Strebinger technique using a Pregl filter tube for the micro scale rather than the filter paper method recommended.

Anthranilic acid gives a normal salt which can be weighed as such and the conversion factor of 18·38% copper makes it suitable for micro-analysis. Similarly, 8-quinoline carboxylic acid[7] forms a normal salt which can be weighed directly and possesses a very favourable conversion factor. By controlling the pH between 3·5–4·0 copper can be separated from cadmium and zinc using this reagent and lead, nickel, cobalt and mercury are without effect, but silver and gold interfere under these conditions.

Copper forms inner complex compounds with a number of other organic reagents and of these quinaldinic acid has been applied to the gravimetric determination of copper on the micro scale. α-Benzoin oxime has been applied to both the titrimetric and gravimetric micro determination of copper, and similarly salicylaldoxime has been applied to the gravimetric micro determination. Hecht and Reissner[8] have compared the respective merits of these last two reagents, and 5 : 7 : dibromo-8-hydroxyquinoline. All the reagents were equally efficient, but they recommended salicylaldoxime because the conversion factor is the most favourable.

The micro method of Spacu and Macarovici[9], where

1 H. Fischer, G. Leopoldi and H. von Uslar. *Z. anal. Chem.*, 1935, **101**, 1.
2 Yoe and Overholser. *Ind. Eng. Chem.* (An. Ed.), 1942, **14**, 148.
3 G. Spacu and P. Spacu. *Z. anal. Chem.*, 1932, **90**, 182.
4 Zanko and Bursuk. *Zhur. Prikkol. Khim.* (J. App. Chem.), 1936, **9** 2297.
5 G. H. Bendix and D. Grabenstetter. *Ind. Eng. Chem.* (An. Ed.), 1943, **15**, 619.
6 Haywood and Wood. *Analyst*, 1943, **68**, 206.
7 Gilbreath and Haendler. *Ind. Eng. Chem.* (An. Ed.), 1942, **14**, 866.
8 Hecht and Reissner. *Mikrochemie*, 1935, **17**, 174.
9 Spacu and Macarovici. *Z. anal. Chem.*, 1935, **102**, 351.

copper is precipitated by benzidine or tolidine in the presence of thiocyanate appears to be of little value, since it can only be applied to pure copper solutions and many other reagents are available free from this defect. Also the precipitate must be ignited to the oxide because of its uncertain composition, thereby losing the favourable conversion factor.

Antimony and Tin

The penetration compound formed by ethylenediamine with chromium chloride has been recommended[10] for the semi-micro determination of antimony. After converting the antimony to the sulphide it is precipitated by this reagent to give the complex $Cr\ en_3\ Sb.S_4$ (en = NH_2-CH_2-CH_2-NH_2), containing 36·48% of antimony, which can be weighed directly. For the determination of tin and antimony in bearing metals and ternary alloys the following semi-micro method has been suggested.[11] Tin is precipitated by cupferron and ignited to the oxide, the antimony is then precipitated and weighed as the compound referred to above.

Iron, Titanium and Aluminium

The following method has been used for the determination of these metals when present together in micro amounts.[12] Iron is first precipitated with oxine in tartaric acid-acetic acid solution. The remaining filtrate is acidified with hydrochloric acid, and the excess oxine is brominated with bromate-bromide, when it forms 5, 7-dibromo-8-hydroxyquinoline, which precipitates the titanium from the acid solution as an inner complex compound. This is filtered off, and more 5, 7-dibromo-8-hydroxyquinoline is added, and the filtrate made alkaline with ammonia, from which the aluminium is precipitated as an insoluble inner complex compound. All the three metals can be weighed in their organic complex form, and by this method all three can be determined on the same sample.

Chromium and Vanadium

Vaughan[13] has put forward micro methods for the colorimetric determination of these two metals in steel, using organic reagents. For chromium the sample is dissolved in acid and the chromium oxidised to chromate. This chromate is then used to oxidise diphenylcarbazide in acid solution when a deep violet red colour is obtained, which is used in the determination. In the case of vanadium in steel, this is first precipitated from solution with ammonium molybdate, and the precipitate dissolved in sulphuric acid. To this solution, after oxidation with potassium chlorate, strychnine in sulphuric acid solution is added, and a violet coloration develops, whose intensity is proportional to the vanadium content.

Zinc

A rapid semi-micro method has been developed[14] for the determination of zinc in tin-lead solders, zinc-tin alloys, and of zinc oxide in certain enamels, using anthranilic acid with which it forms a normal salt. In solders and zinc-tin alloys the tin is held in solution by sodium tartrate, and in white metal alloys iron is first removed by a modified basic acetate process, zinc being neither adsorbed nor co-precipitated by this process. The amounts used are 0·5 gm. for solders, 0·05 gm. for zinc-tin alloys and 0·5 gm. for white metal alloys, and the zinc is finally weighed as the anthranilate. This application to industrial analysis is of interest, since usually anthranilic acid only finds application as a suitable weighing form because it precipitates with a large number of other metals forming normal salts.

Zinc can also be determined on the micro scale with quinaldinic acid, which precipitates it as an inner complex compound from solutions made acid with glacial acetic acid. The complex, which contains 15·37% of zinc, is weighed as such.

A study by Biefeld and Ligett[15] of the optimum conditions for separating semi-micro amounts of zinc from lead and copper with salicylaldoxime, which precipitates all these metals as inner complex compounds under suitable conditions, has shown that, whilst lead and copper can be accurately separated and determined by suitable pH control, zinc, which remains in the filtrate, has finally to be determined by other means, although the separation is exact.

Nickel

One of the earliest organic reagents to be used in metallurgical analysis was dimethylglyoxime for nickel. It must be admitted that although during the last 25 years a large number of organic reagents have been investigated and recommended for various metals, none compares with this reagent for specificity apart from other organic compounds having the dioxime group specific for nickel and which fall in the same class.

Micro analysis using this reagent varies little from the classical macro procedure except in the method of filtration, which was originally worked out by Strebinger. Vaughan (*loc. cit.*) has shown that by using iodine together with dimethylglyoxime the resulting nickel complex is sufficiently soluble to enable the nickel to be determined absorptiometrically, and has put forward a micro method based on this technique.

Magnesium

A rapid semi-micro method for the determination of magnesium in aluminium alloys using oxine has been recommended by Pitts.[16] The magnesium is precipitated as the inner complex salt with oxine from an alkaline cyanide-tartrate solution and is finally determined by bromate titrations. A single precipitation of the magnesium is sufficient in the presence of manganese, copper, zinc, aluminium, nickel, iron and silicon.

Small amounts of magnesium are generally determined absorptiometrically using a suitable organic reagent, but it appears that none of the conventional reagents give entirely satisfactory results. Two methods of determining micro amounts of magnesium have been recently put forward,[17] one of which has a titrimetric and the other a colorimetric finish. In each of these the magnesium test solution is treated with 8-hydroxyquinoline, with which it forms an inner complex compound. In the titrimetric determination this reagent is oxidised with hexanitrato-cerate in perchloric acid solution, and the excess is back titrated with 0·01 N. ferrous ammonium sulphate, using Setopaline C as indicator. Amounts as low as 5 micrograms were determined satisfactorily by this method. In the colorimetric method

10 Spacu and Pop, *Z. anal. Chem.*, 1938, **111**, 254.
11 Mach and Hecht. *Mik. Acta.*, 1937, **2**, 227.
12 Zanko and Bursuk. *loc. cit.*, p. 895.
13 E. J. Vaughan. *Inst. of Chemy. Monograph*, 1942.
14 Anderson. *Ind. Eng. Chem.* (An. Ed.), 1941, **13**, 367.
15 Biefeld and Ligett. *Ind. Eng. Chem.* (An. Ed.), 1942, **14**, 359.
16 Pitts. *Analyst*, 1943, **68**, 133.
17 L. Gerber, R. J. Claassen and C. S. Boruff. *Ind. Eng. Chem.* (An. Ed.), 1942, **14**, 658.

the precipitated hydroxyquinolate is treated with ferric chloride in acetic acid solution and the green colour of the iron hydroxyquinolate measured in the range 5–100 microgram.

The latter method is recommended as greater precision is obtained with fewer operations, and it has recently been applied by Weeks and Todd[18] to the analysis of soils and plant materials. It should be applicable in those metallurgical analyses where magnesium can be readily separated as the hydroxyquinolate and it might also prove applicable to the determination of aluminium where this can be separated as the hydroxyquinolate.

Titrimetric Procedure

Furman and Flagg[19] have investigated the titrimetric determination of metallic complexes precipitated by reagents of the oxime type based on the decomposition of the complex to yield hydroxylamine. These workers developed a bromate-arsenite oxidation technique, which they applied to copper-salicylaldoxime, copper-α-benzoin oxime and nickel dimethylglyoxime, wherein the final oxidation product of the hydroxylamine is a nitrate. This gives a more favourable ratio of standard solution used per unit weight of metal than is usually obtained by oxidation of the hydroxylamine with ferric ion to nitrous oxide. Thus, when salicylaldoxime was used as precipitant it was shown that 1 ml. of 0·1 N. bromate solution was equivalent to 0·4541 mg. of copper and with α-benzoin oxime 1 ml. of 0·1 N. bromate solution was equivalent to 1·0595 mg. of copper. In the case of nickel 1 ml. of 0·1 N. bromate solution was equivalent to 0·2445 mg. of nickel. For the macro determination of copper in steel neither α-benzoin oxime, which is used in a tartaric acid solution buffered with tartrate, nor salicylaldoxime offer any advantage over the usual sulphide precipitation followed by thiosulphate titration. For the micro and semi-micro procedure, however, the use of organic reagents in conjunction with the Furman and Flagg technique would be more advantageous since the conversion factors are much more favourable than in the thiosulphate titration where 1 ml. of 0·1 N. thiosulphate is equivalent to 6·357 mg. of copper.

18 M. E. Weeks and J. R. Todd. *Ind. Eng. Chem.* (An. Ed.), 1943, **15**, 297.
19 N. H. Furman and J. F. Flagg. *Ind. Eng. Chem.* (An. Ed.), 1940, **12**, 738.

Amperometric Titration

The use of organic reagents in conjunction with amperometric titrations offers a useful tool for the semi-micro and micro analysis of metals because of the accuracy with which dilute solutions can be titrated. Nickel over the range 0·06 to 0·3 mg. can be determined accurately, using dimethylglyoxime as the titrant.[20] If, however, cobalt is present in appreciable amounts it has to be separated. The method has been used for determining nickel in steel, but in this case the iron is first separated by ammonium benzoate.

Cobalt, copper and palladium have been determined amperometrically, using α-nitroso β-naphthol. As an example of the sensitivity of the method, a 0·0002 molar solution of cobalt can be titrated with an accuracy of 1 to 2%. Zinc, aluminium and manganese do not interfere, but when nickel is present, although it is not precipitated, it gives high results. Salicylaldoxime and α-benzoin oxime have also been used for the amperometric titration of copper, and the accuracy of the results obtained, together with the specificity of these reagents, suggests that the method would be applicable to metallurgical micro analysis.

20 I. M. Kolthoff and A. Langer. *J.A.C.S.*, 1940, **62**, 211, 3172.

Micro-Volumetric Apparatus

A REVIEW of many varying types of micro-volumetric apparatus was given at the Sheffield Symposium on Microchemistry, as reported some time ago in METALLURGIA. This review has now been published in full[1] and forms a very valuable addition to the literature of microchemistry. Numerous diagrams illustrate the text, and there is a full set of references.

Sintered Glass Filters

A NOTE of interest in connection with our description of micro sintered-glass filters with ground joints[2] has appeared recently.[3] It describes a sintered-glass filter crucible now in production which has the outside shaped to the form of a *standard* ground-glass joint, and which will therefore fit into a receiver the neck of which consists of the female half of the joint. The crucible is large (capacity 30 mls.), but the extension of the principle to micro and semi-micro filters is obvious, and will, we hope, not be long delayed.

The note also points out that the risk of the crucible sticking in the receiver when used with bituminous solutions may be obviated by wrapping a piece of cellophane around the joint before assembling. It is claimed that this does not unduly affect filtration under reduced pressure.

1 G. H. Wyatt, *Analyst*, 1944, **69**, 81.
2 METALLURGIA, 1944, **29** (March), 276.
3 D. M. Wilson. *Chem. and Ind.*, 1944, No. 14 (April 1), 129.

The Micro-Analysis of Fuels

SOME account was given in our last issue of methods which can be applied to solid fuels. Similar modifications have been developed for gaseous fuels.[4]

Gases may be dealt with in three ways: (1) by low pressure methods, where the alterations in pressure are measured by, e.g., a McLeod gauge; (2) low-temperature distillation methods, the composition being determined from pressure-temperature curves; and (3) capillary burette methods, the diminution in volume at ordinary temperature and pressure being measured after the removal of each constituent. For routine analysis the third class is to be preferred because of the less elaborate apparatus. Typical absorbents for gases are solid phosphorus pentoxide for water vapour, solid caustic potash for carbon dioxide, white phosphorus for oxygen, porous porcelain soaked in sulphuric acid catalysed by 6% uranium sulphate for ethylene and the unsaturated hydrocarbons. Carbon monoxide may be oxidised by cupric oxide-caustic potash to carbon dioxide, and so removed, while paraffins, hydrogen and nitrogen may be estimated by explosion analysis.

4 R. Belcher and C. E. Spooner. *Iron and Coal Tr. Rev.*, 1944, **146**, 165.

METALLURGICAL DIGEST

Malleable Castings

By O. W. Simmons, P. O. Rosenthal, and C. H. Lorig

A STUDY was made of the effect of temperatures upon the mechanical properties of malleable iron with a view to extending the useful application of this material in the war effort. The work was divided into two main parts: (A) Determination of the impact properties of malleable iron over the temperature range from room temperatures to — 50° F. (— 40° C.). (B) Determinations of the tensile and impact properties of malleable iron over the temperature range from room temperature to 1,200° F. (650° C.). The first part of the tests were carried out at 75° F. (24° C.), 0°, — 10°, — 20°, — 30°, — 40°, and — 50° F., using keyhole notched Charpy specimens of single and double width, wedge impact specimens, and tensile impact specimens. These tests were made to show the impact resistance of both notched and unnotched specimens of malleable iron at sub-atmospheric temperatures. The second part of the tests was conducted at temperatures of 75° F. (24° C.), 200°, 400°, 600°, 800°, 1,000° and 1,200° F. (650° C.) and involved tensile tests, tensile impact tests, notched bar impact tests, and wedge impact tests at each of the stated temperatures.

The types of malleable iron tested are given in Table I. Impact test specimens tested below normal temperature were stored in vacuum jars at the desired temperature for at least one half hour prior to testing, the temperature being obtained by immersing the specimens in acetone and then adding crushed dry ice until the desired temperature was obtained. Impact specimens tested above 200° F. were immersed in a molten salt bath at the desired temperature for periods of at least one half hour prior to testing, removed from the bath by special tongs, placed in the testing machine and broken in a total time never exceeding 4 secs. In the wedge test the specimen was maintained at the desired temperature by directing a continual flow of liquid at the temperature over the specimen throughout the test. High temperature control was maintained by immersing the specimen in a salt bath at the desired temperature between each blow of the tup and quickly returning it to the test machine, as soon as the proper temperature had been reached. Tests at room temperature (Table II) were carried out under normal conditions, and tensile tests at elevated temperatures in an electric furnace maintained at the desired temperature.

TABLE I.—TYPES OF MALLEABLE CAST IRON TESTED.

Mark.	Type.	Composition.				
		T.C.	Si.	Mn.	S.	P.
A	Standard	2·30	1·05	0·302	0·084	0·162
B	Standard	2·33	0·98	0·34	0·078	0·168
C	Short cycle	2·32	1·31	0·41	0·092	0·071
D	Short cycle	2·38	1·46	0·35	0·072	0·097
G	Cupola	3·25	0·65	0·57	0·156	0·10
P	Pearlite	2·33	0·98	0·34	0·078	0·168
E	Pearlite	2·27	1·22	0·48	0·17	0·11
F	Pearlite	2·23	0·96	0·81	0·09	0·15
H	Pearlite	2·23	0·14	0·64	0·08	0·11

The notched-bar toughness of all the irons decreased gradually at sub-atmospheric temperatures. In only one iron, B, was this increasing brittleness displayed by a sudden drop in the double-width Charpy bar values, similar values in all other irons being approximately twice the values obtained from the single-width bars. Unnotched specimen values also dropped with temperature, although the loss was slight, and all the irons, except cupola malleable G and the pearlitic malleables E and F were substantially resistant to impact. The detrimental effect of combined carbon on toughness was shown by the improvements wrought on the unnotched specimen and wedge-test results for iron D after annealing to remove pearlitic areas. The standard malleable irons did not appear to be particularly sensitive in the tensile impact tests, but the pearlitic malleables behaved more erratically.

The "Flecto" treatment given to the plain and cupola-malleable irons considerably enhanced the ability of irons A and B to absorb impact energy in the notched condition, although the unnotched Charpy specimens were apparently unaffected by this treatment. In the case of the notched specimens, the air quench from 1,200° F. (650° C.) was somewhat more efficacious than the water quench from the same temperature. The treatment had little effect on impact properties at normal temperature and above, and its effect on the other irons was negligible.

At elevated temperatures the best combination of properties in all irons occurred in the temperature range of 75° to 200° F. Above these temperatures, ductility either remained constant or fell off up to about 600° F.; Charpy values decreased continuously to about 1,000° F.; wedge-test results generally reached a low value at from 400° to 800° F.; and tensile impact values dropped steadily to about 800° F. The strength was maintained fairly well to 600° F., but above this temperature it fell off rapidly while the ductility correspondingly increased.

If the irons are compared on a basis of types, the normal phosphorus, standard malleable irons, A and B, had satisfactory strength and ductility from normal temperature to 600° F. (315° C.). These irons had good impact properties over a considerable range of temperature, iron A possessing good resistance in the wedge and Charpy bar tests from — 50° to 300° F., and iron B from — 20° F. to 400° F. The low phosphorus, short-

From *The Foundry*, 1943, vol. 71, No. 10, pp. 102–104, 190; No. 11, pp. 122–125, 190–192; No. 12, pp. 106–108, 202–204.

TABLE II.—NORMAL TEMPERATURE PROPERTIES OF MALLEABLE IRONS AS RECEIVED.

Mark.	A.	B.	C.	D.	G.	E.	F.	H.	P.
Tensile Tests.									
Ultimate stress, tons per sq. in.	24·9	25·3	23·9	23·5	21·1	41·5	40·0	40·0	33·6
Proportional limit, tons per sq. in.	8·7	8·9	10·5	6·5	6·0	16·7	12·2	18·5	10·5
Elongation, % on 2 in.	28·3	19·5	16·0	12·5	6·0	8·5	18·0	12·5	10·0
Charpy Impact.									
Unnotched single width, ft.-lb.	89·0	80·0	76·8	61·5	23·7	18·7	9·1	50·5	50·4
Notched, single width, ft.-lb.	8·1	6·9	6·6	5·4	4·6	2·1	2·5	5·4	5·9
Notched, double width, ft.-lb.	15·5	11·5	12·9	10·5	7·9	3·7	8·6	9·0	10·5
Wedge Tests.									
Blows of tup	30+	26	30	3	1	5	3	36+	30+
	30+	30	4	4	—	9	7	46+	30+
	—	—	11	8	—	—	—	—	—
	—	—	15	10	—	—	—	—	—
Tensile Impact.									
Energy, ft.-lb.	124·5	80	64·3	57·0	11·8	43·6	17·2	76·5	49·1
Elongation, % on 2 in.	25	15·5	13·8	12·3	3·5	6·0	2·2	9·5	7·5

cycle malleable irons, C and D, had about the same strength, but lower ductility at similar temperatures. These irons, when machined and free from combined carbon, had approximately the same impact properties at low temperatures as the normal phosphorus irons, except that iron C behaved erratically in the wedge test at all temperatures, and iron D had poor resistance to impact until given a second stage annealing to remove traces of combined carbon.

The cupola malleable iron showed little changes in tensile strength in the range 32° to 600° F. (0° to 315° C.), while at higher temperatures the strength decreased rapidly. At no temperature did it possess good resistance to shock.

The several types of pearlitic malleable irons had high strength combined with considerable ductility over the temperature range — 30° to 600° F., but above which there was a drop in strength and an increase in ductility. These irons had good shock resistance near normal temperature, but they rapidly deteriorated in this respect, as the temperature decreased and, at a slower rate, as the temperature increased. As a group, their impact properties and ductility were inferior to those of the standard malleable irons at both high and low test temperatures.

The Influence of Carbon Content on the Hot Zincing of Sheet Steel

By W. Pungel

EXPERIMENTS carried out on 2 mm. sheet steel, which was available in eight different batches with carbon content ranging from 0·06 to 0·78%, are described. Samples (20 × 20 cm.) were cut from each batch and were subjected to the following preliminary treatment in lots of 12 :—

(*a*) Sandblasting only.
(*b*) Sandblasting followed by annealing at 750° C. for one hour.
(*c*) Normalised only.

Each lot of 12 was next pickled in 20% HCl and then hot zinced at 430–440° C. (30 secs. immersion period) six of the samples being treated by the so-called dry process, the wet process being adopted for the remainder. (In the dry process the sample is sprinkled with NH_4Cl powder and dried before immersion, whilst in the wet process, the pickled and still wet specimen is immersed, the bath in this case being covered with a surface layer of NH_4Cl and $ZnCl_2$ flux).

After zincing, the samples were subjected to the following tests :—

(*a*) Determination of thickness of deposit (chemical method).
(*b*) Adhesion tests (Ericson cup and folding tests).
(*c*) Examination of structure of deposit (sectioned).
(*d*) Bending fatigue strength.

The author concludes that provided the sheet-metal surface is thoroughly cleaned by sandblasting before pickling and the pickling liquor removed before dipping, the carbon content of the sheet exerts no detrimental effect on the zinc deposit and affects neither its uniformity nor adhesion. The thickness of the resulting deposit was practically the same in the wet and dry process, and averaged about 700 gm./m.². Uneven deposits, however (black patches) result if the sheet is not sandblasted prior to pickling, and in this case there is some evidence that the nature of the zinc deposit deteriorates with increasing carbon content of the sheet. This is evidently due to uneven attack of the pickling solution and attempts to overcome this difficulty by altering the nature of the latter have failed so far.

From *Stahl und Eisen*, vol. 64, No. 7, Dec. 17, 1944, pp. 101–105. By courtesy of R.T.P. 3, Ministry of Aircraft Production.

Surface Structure Markings on Al-Mn and Al-Mg-Si Sheet Metal after Anodic Treatment

DURING the anodic treatment (d.c. sulphuric acid electrolytes) of Al-Mn alloy sheet, dark cloudy markings are occasionally produced, especially if the material is semi-hard. Surface markings are also found, although more rarely, when anodising Al-Mg-Si sheet. In this case, however, the marking is not dark, but speckled. The chemical composition of sheets exhibiting this abnormality does not differ in any way from that of other sheets yielding the normal white oxide film on treatment. It appears that the discolouration of Al-Mn sheet is due to the supersaturation of the mixed crystals with Mn at their boundaries. This may lead to an uneven distribution of Mn already in the casting if the latter is annealed incorrectly.

The segregate once formed will persist in the rolled sheet and on subsequent anodising produces a dark cloudy deposit of manganese oxide. The cure of the trouble therefore lies in a close temperature control of the cast alloy prior to rolling. The casting should be carried out quickly and the annealing temperature prior to rolling should not exceed 450° C. for 4 hours, at an actual rolling temperature of 350° C. Slow cooling of the casting (of the order of 30 mins.) and lengthy annealing periods (of the order of 24 hours) favour the breaking up of the mixed crystal and the formation of unevenly dispersed segregates may lead to troubles during subsequent anodising.

In the case of Al-Mg-Si alloys the Mg_2Si segregate is already formed during the cooling of the casting. On account of the higher mobility of the Mg and Si atoms compared with those of Mn, however, marked difference in concentration of segregate producing an uneven oxide film on subsequent anodisation occur only relatively rarely. Suitable heat-treatment of the original casting again obviates the trouble.

From *Z. f. Metallkunde*, vol. 35, No. 5, May, 1943, pp. 117–120. By courtesy of R.T.P. 3, Ministry of Aircraft Production.

The Effects of Quenching Temperature on the End-Quench Hardenability Test

By C. E. Jackson and A. L. Christenson

THE relation of time and temperature for various distances along a standard end-quench hardenability test specimen was determined for quenching temperatures ranging from 815° to 1,150° C. These measurements were made, using stainless steel (18–8 type), a low-carbon nickel steel, and several low-carbon steel specimens. Several end-quench hardenability specimens were made in duplicate or quadruplicate from each steel and quenched from the various temperatures. To obtain a uniform grain size test-bars in a series were heated to 1,150° C. and then either quenched or transferred to a furnace at lower temperature before quenching.

In general, standard A.S.T.M. quenching experiment and procedure, with the exception of quenching temperatures, were used in all the end-quench hardenability tests. In order to obtain a more exact measurement of hardness changes, the Vickers' hardness method was used in preference to the Rockwell hardness test. Two methods for recording temperature and temperature changes were used. The first of these, a high-speed temperature recorder, was used to obtain most of the data for the low-alloy nickel-steel, and the second a 35 mm. movie camera to obtain the data for the 18–8 specimens. The effect of quenching temperature on cooling rate at 720° C. for end-quench hardenability test specimens of the austenitic stainless steel are shown in Fig. 1. In Table I are given the hardenability data for the nickel and low-carbon steels.

The data that are presented clearly show that the quenching temperature for the end-quench hardenability test-bar is important, especially for steels of low hardenability, and the cooling rates follow closely the relative cooling rates predicted by the ideal quench at distances close to the end of the test-bar. The effect of quenching temperature beyond ½ in. is less important, and is not great for the narrow range of temperatures used in ordinary hardening, but is present and cannot be neglected in comparative hardenability studies.

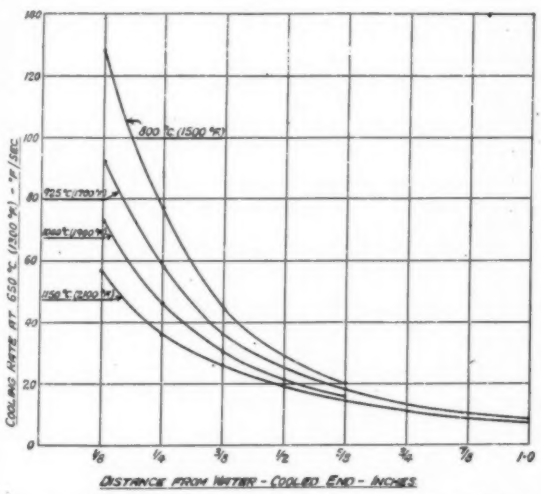

Fig. 1.—Effect of quenching temperature on cooling rate at 650° C. (1,300° F.).

The relation of quenching temperature and time to cool from 600° to 480° C. follows closely the effect of quenching temperature on the cooling rates at 700° C., and a marked effect of quenching temperature on the time to cool from 600° to 480° C. is still noticeable at ½ in. distance along the bar. Except in a few isolated cases, the quenching temperature was found to have little effect on the hardenability of deep-hardening steels, because the half-hardness point for deeper hardening steels occurs at such a distance along the end-quench hardenability bar that there is little or no difference in the severity of quench for various quenching temperatures.

In an ideal quench of an infinite plate (severity of end-quench factor becomes infinite and air cooling negligible) the relative cooling rates when quenched from various temperatures are independent of distances from the surface of the plate. In the end-quench test, as the severity of the end-quench decreases in value, and the air-cool factor increases, the relative cooling rates depend upon the distances from the quenched end of the bar, and the quenching temperature have less effect as the distance becomes greater. The effect of quenching temperature on the end-quench test assumes its greatest importance in the quenching of low-hardening steels, and the more nearly the quench of a section approaches the ideal quench of an infinite plate the greater is the effect of quenching temperature on the cooling conditions.

TABLE I.—COMPOSITION AND HARDENABILITY DATA.

Composition.						50% Martesite Hardness.	Quenching Temp., °C.	Grain Size No.	End-quench Hardenability Distance, In.	Ideal Diameter In.
C.	Mn.	Cr.	Ni.	Cu.	Al.					
0·17	0·45	—	1·43	—	—	285	1,150 925	1·7 —	0·21 0·27	1·70 1·95
0·36	0·88	0·10	—	0·09	0·001	375	1,150 925	1·6 —	0·28 0·33	2·00 2·20
0·20	0·42	0·04	—	0·05	—	300	1,150 925	1·8 —	0·10 0·12	1·20 1·30
0·31	1·46	0·05	0·09	0·24	0·05	350	1,150 840	3·6 —	0·25 0·34	1·90 2·25
0·30	0·94	0·10	—	0·09	0·001	350	1,150 870	1·8 —	0·19 0·23	1·60 1·80
0·28	0·42	0·05	0·06	0·16	0·005	345	1,150 870	3·7 —	0·12 0·135	1·30 1·40
0·30	0·49	0·06	0·08	0·27	—	350	1,150 870	2·8 —	0·135 0·18	1·40 1·60
0·23	0·38	0·04	0·09	0·09	0·002	330	1,150 870	3·5 —	0·16 0·185	1·50 1·60
0·30	0·65	0·06	0·02	0·15	—	350	1,150 870	2·9 —	0·14 0·18	1·40 1·55
0·29	0·65	0·03	0·02	0·04	0·04	340	1,150 870	2·2 —	0·16 0·20	1·50 1·65
0·36	0·88	0·06	0·06	0·21	—	360	1,150 870	4·1 —	0·21 0·25	1·70 1·90

From *Metals Technology*, 1943, vol. 10, No. 8, and A.I.M.E. *Technical Publication* No. 1647, 11 pp.

Influence of Improved Magnetic Alloys on Design Trends of Electrical Instruments

By J. S. Wilson and J. M. Whittenton

THE authors review briefly the magnetic alloys which have been utilised previously as magnets in D.C. permanent-magnet moving-coil small-panel indicating instruments, and describes the properties of a new cobalt-molybdenum-iron alloy which has definite advantages as a permanent magnet in electrical instruments because of its high magnetic strength and good machining qualities. The utilisation of this new cobalt-molybdenum-iron alloy for the first time as a permanent magnet in an indicating instrument is described and illustrated. Comparison with a similar instrument having a magnet made of chrome steel demonstrates the improvement in over-all performance and reliability of a given rated instrument using this new magnetic alloy. Particular emphasis is given to the increased "mechanical factor of merit" which is a measure of instrument reliability and other improvements which result from the use of this material.

From *Electrical Engineering*, U.S.A., January, 1944.

Torsion Fatigue Testing Machine for Large Parts

It is known that the torsional and bending fatigue strength of a specimen depends markedly on its cross-section. Thus the torsional fatigue strength of a crankshaft with a journal diameter of 245 mm. is only about half that of a model made of the same material to one-sixth scale. It has therefore been necessary to design fatigue testing machines capable of handling large specimens, and the author describes a type of torsional machine capable of exerting a periodic twisting moment of up to ± 12,000 kgs. superimposed on a static moment of up to 12,000 kgm.

The amplitude of twist is ± 6°, and high-grade steel shafts up to 160 mm. diameter can be tested. The machine is operated by a D.C. shunt motor of 80 kw., the normal speed being 800 r.p.m. For starting up, a two-stage gearbox with reduction ratios of 1 : 24 and 1 : 6 respectively is used, the motor being under Leonard control. At the operational speed of 800 r.p.m., the gears are uncoupled electromagnetically and the drive is direct.

From *Z.V.D.I.*, vol. 88, No. 3/4, Jan. 22, 1944 p. 54. By courtesy of R.T.P. 3, Ministry of Aircraft Production.

Structure and Creep Characteristics of Cast Carbon-Molybdenum Steel at 510° C

By H. E. Montgomery and J. Urban

THE relationship of creep characteristics to certain structures in carbon-molybdenum cast steel has been investigated in connection with more extensive laboratory studies of the various effects of heat-treatment on structural and physical properties. The steel used contained 0·26% carbon, 0·40% silicon, 0·64% manganese, 0·50% molybdenum, with small amounts of chromium, nickel, copper and aluminium. This steel was so treated that it was either entirely in the acicular condition with no ferrite grains or in the pearlite condition. By using such structures it was felt that the relative creep-resisting characteristics of each could be ascertained. Heat-treatments to produce the desired structures and corresponding normal temperature physical properties are given in Table I. All test specimens had a preliminary treatment of 5 hours at 1,980° C., furnace-cooled to 1,870° C. for 5 hours and then air-cooled.

Creep curves for the various treatments are given in Fig. 1, and show that great differences in behaviour in creep occur. At the same temperature, 510° C., and load of 5·4 tons per sq. in., the relative order of merit in sustaining load is—

Treatment.	Structure.	Creep Rate % per 100,000 Hours over 500 Hours to 2,000 Hours.
No. 114	Coarse acicular	1
No. 112	Fine acicular	3·5
No. 115	Coarse pearlite	7·5
No. 113	Fine pearlite	48

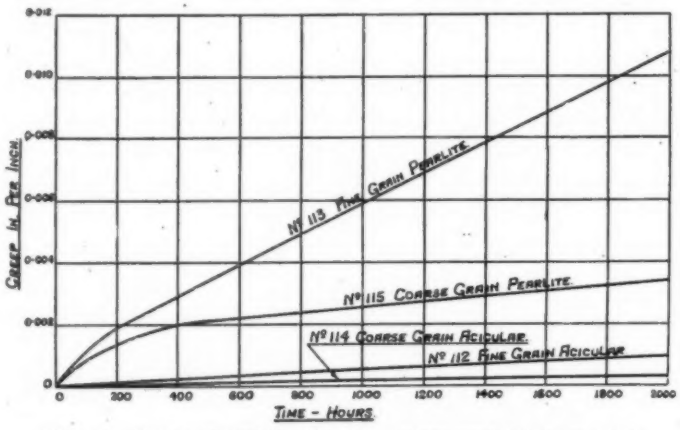

Fig. 1.—Creep strength of cast carbon-molybdenum steel at 510° C and 5.4 tons per sq. in.

The acicular structures seem to outweigh the effect of grain size, although in each case, acicular or pearlitic, the coarse grain is superior for a given intergranular structure. The creep bars after test show a slight increase in Rockwell hardness.

TABLE I.
HEAT-TREATMENTS AND PHYSICAL PROPERTIES OF CAST CARBON MOLYBDENUM STEEL

No.	Treatment.	Grain Size-Average.	Micro-structure.	Yield-point, Tons per Sq. In.	Tensile Strength Tons per Sq. In.	Elongation, %.	Rockwell Hardness B.	
							Before Creep.	After Creep.
112	870° C., 3-hour quench into tin at 435° C. hold 2-hour temper at 650° C., 5 hours.	8	Fine grained acicular.	36·0	44·5	16·3	90	91
113	870° C. 3-hour quench into tin at 650° C. hold 5 hours.	8	Fine grained pearlitic.	27·2	35·7	22·0	82	83
114	1,100° C. 5-hour cool to 870° C. quench into tin at 435° C. hold 2-hour temper at 650° C., 5 hours.	4 to 5	Coarse grain acicular.	31·7	41·6	17·3	93	95
115	1,100° C. 5-hour cool to 870° C. quench into tin at 650° C. hold 5 hours.	5	Coarse grain pearlitic.	24·7	33·5	26·4	84	85

The acicular structure is a transition structure intermediate between pearlite-ferrite and martensite, and has proved stable at 510° C. for long periods. Test specimens with the acicular structure have been tested in creep at 940° C. under loads that gave 2·5% in 100,000 hours, and the structure showed no breakdown at 940° C. in 2,500 hours, the total time of test, as evidenced both by structural examination and by hardness tests. In regular manufacturing practice, the occurrence of an acicular structure indicates a change in transition temperature due to some condition inherent in the affected heat. The causes are not fully known, but experience has shown that reactions during the refining and deoxidation of the metal are responsible in part. In the investigation carried out it was necessary to use delayed quenching to produce the desired structural and grain-size combinations.

From *Bulletin American Society for Testing Materials*, 1943, No. 125, pp. 13–16.

The Influence of High Frequency (Supersonic) Longitudinal Vibrations on the Magnetic Response of Nickel

By G. Smid and J. Jetter

THE experiments covered nickel wires ranging in diameter from 0·5 to 2 mm., which were suspended vertically and subjected to longitudinal vibrations of a frequency of 19,500/sec. by means of a nickel tube oscillator attached to the lower end and operating by magnetrostriction. The upper end of the wire was attached to a steel band passing over horizontal rollers and carrying a scale pay for loading the wire statically. Reflexion of the longitudinal waves at the upper end of the wire was prevented by covering the attachment with Chatterton compound. The vibration amplitude was measured by observing the displacements of a reference point on the wire (suitably illuminated) in a microscope. It was found that this amplitude corresponded to that of the upper end of the oscillator and could therefore be measured by electromagnetic induction. The amplitude was varied by changing the power input of the oscillator, the change in extension corresponding to a range of stress amplitudes from 0 to 3 kg./mm². By means of the scale pan loads, the wire could also be subjected to a series of constant static loads from 0 to 5 kg./mm² simultaneously with the excitation. The magnetic response of the wire (I/H curve) was traced out by a cathode ray oscillograph working in conjunction with a Forster ferrograph. On this oscillograph, the horizontal deflection corresponds to changes in the applied field strength H, whilst the vertical deflection record, the changes in the magnetisation Is The ferrograph is operated with alternating current of 50 cycles/sec., which is also the periodicity of the observed I/H curves. The magnetic field thus changes from zero to a maximum value in 1/200 sec.

Before the measurements, the Ni wires were annealed in an atmosphere of H_2 for 2 hours at 800° C., and quenched in H_2 at room temperature. The initial permeability of the wires was of the order of 130, but diminished to about 40 with continued mechanical excitation (age-hardening).

Most of the experiments were carried out in weak magnetic fields (H_{max} = 0·2 Oersted). Under these conditions, in the absence of static load and high-frequency excitation, there is practically no hysteresis and the magnetisation curve shrinks to such narrow dimensions that in general only two parallel lines enclosing a very narrow gap can be detected. As soon as the oscillation, however, is started up the loop broadens out, becoming wider as the oscillation or stress amplitude increases. After a certain maximum amplitude is reached (usually of the order of 1 kg./mm².), however, the loop shrinks again and approximates to its original narrow shape when its stress amplitude reaches about 2 kg./mm². The loop now is, however, more tilted, and I_{max} considerably greater than in the original (unexcited) state. These characteristics are retained if the wire is subjected to a constant tensile load whilst subjected to high-frequency excitation. The size of the loop is, however, reduced by the static load which evidently appears to oppose the vibratory effect. For the same stress intensity, however, the static load produces a much smaller numerical effect. Thus, in the absence of high-frequency excitation, a static tensile stress of 1 kg./mm². reduces the maximum magnetisation of the wire by about 25%. On the other hand, in the absence of static load a high-frequency stress vibration with an amplitude of 1 kg./mm². increases I_{max} 10 times! From this it might appear at first sight as if the pressure component of the high-frequency oscillation were responsible for the increased effect. This pressure component can, however, be made to disappear by subjecting the wire to a tensile load in excess of the excitation amplitude. The wire is now always fluctuating in tension, but still shows a six-fold increase in maximum magnetisation compared with no load conditions. Quite different results are, however, obtained if the magnetisation is carried out in strong fields of the order of 50 Oersted. Increasing the amplitude of the high-frequency stress (no static load) now progressively reduces the width of the loop without, however, affecting the general shape or I_{max} appreciably. The diagram approaches more and more to the ideal shape as the stress amplitude is increased to beyond 2 kg./mm². It is evident that the high-frequency oscillation "frees" formerly irreversible processes in the material already at very weak values of the field H.

Increasing the static load in the absence of high-frequency oscillation, however, both closes the loop and alters its shape, the material evidently becoming increasingly difficult to magnetise.

The interrelation between stress and magnetic behaviour thus depends markedly on the frequency of the stress. This is also shown by the fact that soft annealed Ni will age harden at a very much smaller stress when the latter is applied at high frequency than when applied statically.

Magnetic tests of the type described are hoped to lead eventually to a better understanding of the changes in material structures under load. Their great advantage lies in the fact that they give average results over the whole volume, whilst electron diffraction tests deal only with surface effects.

From *Z. f. Elektrochemie*, vol. 48, No. 10, Oct., 1942, pp. 513–522. By courtesy of R.T.P. 3, Ministry of Aircraft Production.

The Heat-Treatment of Steel Under Pressure

AMONG the subjects discussed at the Symposium, which included questions connected with the heat-treatment in protective atmospheres, and the heat-treatment of war emergency substitute steels, was the subject of the heat-treatment of steel under pressure.

The application of pressure to the steel during heat-treatment operations affects both the changes which occur during heat-treatment and also the structure of the steel. The compression of heated steel improves the soundness of the structure, and eliminates defects of primary crystallisation. This improvement remains unaffected by subsequent heat-treatments. The compression of heated steel has been studied by two Research Institutes as a means of improving the properties of cutting tools.

As far as the microstructural changes in the steel are concerned, it has been found that compression from all sides during quenching leads to an increase in the amount of residual austenite, and a certain shifting of the critical points. Pulsating pressure, on the other hand, favours the transformation of the austenite.

Tempering under pressure results in the retardation of processes associated with an increase in volume. If the pressure is applied only from two sides, the decomposition of the austenite is more rapid than if the pressure acts from all sides.

The employment of pressure during the quenching and tempering of the steel thus constitutes a means of controlling and attaining a particular structure which may be required in the steel.

Practical recommendations regarding the quenching of tools under pressure in closed dies specify a pressure of between 140 and 160 kg./mm². The part should be heated to the usual quenching temperature and should then be transferred as quickly as possible to the die in which it should be allowed to cool to a temperature of 40° to 50°, while maintaining the pressure at the specified value. The dies which should be in several parts should be made of hard, heat-resisting tool steel. The punches should be of high-speed steel heat-treated to a hardness of 60 Rockwell C.

For tempering under pressure, the part, prior to normal tempering, may be subjected to short time (10 to 30 secs.) and repeated (1 to 10 times) application of unilateral pressure at some temperature below the tempering temperature. Alternatively, the part may be subjected to unilateral pressure during the whole of the heating up, holding, and cooling down periods of the tempering treatment.

Flat parts can be compressed between steel plates, thin copper or aluminium sheets being placed between the plates and the part. Parts having a more complicated form can be compressed in a die filled with an only slightly compressible powder (powdered ferrochrome, quartz sand, or the like). The pressure required during tempering varies between 100 and 160 kg./mm², depending on the stability of the austenite.

To improve the soundness, especially of cast steel, the latter may be subjected to compression in a closed die. Frequently this treatment can be combined with the quenching of the steel. The pressure required is beween 140 and 160 kg./mm², and the temperature is the forging temperature of the steel. The effect obtained is not markedly dependent on the time of application of the pressure.

Resolutions of the Second All-Union Symposium on Stakhanovite Methods of Heat-treatment of Ferrous Alloys. *Metallurgizdat*, 1942.

Powder Metallurgy

By T. E. Lloyd

POWDER metallurgy has grown in stature as a means for manufacturing finished and semi-finished products. The method of compressing metallic powders in dies and heating the resulting compacts to temperature below their melting-point to obtain products of desired shapes offers raw material savings, savings of machine-tool and labour costs and certain definite inherent advantages in the composition of the finished physical product. The types of metallic powders that are pressable are extensive, but the powders used on a large scale are almost invariably the product of the reduction of metal salts by gases, electrolysis or by atomisation. The powders must show definite physical and chemical characteristics in order to be suitable to powder metallurgy, mainly purity.

Some metal powders require an absolute clean surface of the particles in order to get ductility and tensile and shear strength in the finished part. Generally, metal purity is above 99% in powder metallurgy, with such powders as tungsten running 99·99% pure. Compressibility of powders is also important, as is the apparent density of the powders. Many types of small parts are now being made by this powder metallurgy technique, and tolerances can be held as close as 0·001 in. (1/40 mm.). Various combinations of metals, non-metals and non-miscible metals are possible. Among the powder metallurgy parts now being made are gears, bearings, screens, filters, contact points, copper-carbon brushes, radio parts and various brass, steel and aluminium parts. There are still many problems in manufacturing technique that are unsolved. However, research is being carried on.

Different methods of moulding powders to solid parts are: Cold-pressing and sintering, frequently followed by sizing operations; hot pressing into final shape by pressing and sintering; and metal working old cold-pressed and sintered blanks. The part must be one that is widely used, because dies for moulding powder parts are costly. Parts should be simple in design and free of re-entrant angles, and so small that high unit pressures can be attained without exceeding capacity of available presses. Dimensions in the direction of pressing should be kept thin, held, if possible, to ½ in. (13 mm.) in thickness or less. Wide variations in section of any one piece may cause warpages in sintering, because of the differences in shrinkage. Metals with oxides difficult to reduce should be avoided.

Some of the developments during the past year covered the use of iron and aluminium powder moulding techniques, as well as the process of alloying that takes place during sintering and annealing of pressed metal powder. Aluminium powder has not been employed extensively in pressed powder art, because (1) it oxidises readily, forming a film of highly refractory oxides that is likely to interfere in powder metallurgical work; (2) during compression, aluminium and aluminium-alloy powders tend to adhere or cold-weld to die walls; and

"Metallurgy in 1943," by T. E. Lloyd in *The Iron Age*, January 6, 1944.

(3) aluminium-alloy powders are harder than elemental aluminium and have some susceptibility to age-hardening. Several grades of atomised elemental aluminium powders pressed at high pressures yielded specimens with properties approaching those of wrought-annealed commercial aluminium. Various combinations of aluminium with copper, magnesium, manganese and other alloying elements were tried. On the whole, the development of powder metallurgy of aluminium is not yet as far advanced as that of other metallics.

Technical Cohesive Strength of Metals

By D. J. McAdam and R. W. Mebs.

IT has been shown that the technical cohesive strength of a metal cannot be represented by a single stress value, but that it comprises an infinite number of values corresponding to the infinite number of possible combinations of the principal stresses. The technical cohesive strength thus comprises an infinite number of technical cohesion limits, each representing a specific combination of stress at fracture. It has also been shown that plastic extension causes a continuous increase in the technical cohesive strength. The data upon which these conclusions have been made were obtained from several carbon steels and data for alloy steels and non-ferrous metals are lacking. There is also a lack of data relating to the influence of the depth, angle, and root radius of the notch on tensile properties and of the relative effect of the transverse radial stress and the stress concentration induced by notches.

An experimental investigation has been made of the tensile properties of notched specimens of some ferrous and non-ferrous materials, and the influence of the combination of principal stresses and of plastic extension on the technical cohesion limit, ultimate stress, yield stress and ductility studied. The materials included in this investigation were oxygen-free copper, Monel metal, a 13·2% chromium-nickel steel, a 0·2% carbon steel (S.A.E. 1020) and a 0·04% carbon steel. The composition, mechanical treatment and heat-treatment of these materials are given in Tables I and II. Most of the tests were carried out on a pendulum-hydraulic testing machine of 50,000 lb. capacity.

Diagrams were first obtained showing the influence of notch angle, notch depth and root radius on the yield stress and ultimate stress of copper and Monel metal. The test specimens used had angles ranging from 180° (unnotched) to very small angles, in some cases under 20°, and the root radius for most of the specimens was about 0·01 in. For some specimens, however, the root radius was much smaller, ranging from 0·001 in. to 0·004 in.

TABLE I.—COMPOSITION AND MECHANICAL TREATMENT.

Material.	Condition.	Composition.						
		C.	Fe.	Ni.	Cu.	Cr.	Mn.	Si.
Oxygen free copper	Cold rolled	—	—	—	99·97	—	—	—
Monel Metal	Cold drawn	0·18	1·24	Dif.	28·46	—	0·94	0·10
13·2 Cr-Ni steel	Hot rolled	0·09	Dif.	2·06	—	13·3	0·48	0·26
0·2% carbon steel	Hot rolled	0·20	Dif.	—	—	—	0·60	0·20
0·04% carbon steel	Cold drawn	0·045	Dif.	—	—	—	0·31	0·24

All the curves of yield stress and ultimate stress have an initial use. Some of the curves representing shallow notches, however, become nearly horizontal as the notch angles is decreased below 120° and a few eventually turn downwards. With these exceptions all the curves rise continuously at a decreasing rate, because of the dominant influence of the increasing radial-stress ratio. Generally, the deeper the notch and the smaller the root radius, the higher is the course of the curve. The curvature is less for radii of 0·004 in. and 0·001 in.

TABLE II.—HEAT TREATMENTS.

Material.	Treatment.
Oxygen free copper	425° C. for 5 hours, cool in air.
Monel Metal	750° C. for 1 hour, cool in air.
13·2 Cr-Ni steel	670° C., cool in furnace.
0·2% carbon steel	885° C. for 1 hour, cool in water.
	475° C. for 2 hours, cool in air.
0·04% carbon steel	950° C. for 1 hour, cool in furnace.

than for radii of 0·01 in., but a linear relationship was not found for any notch depth or radius. Any interruption to the rise of a curve of ultimate stress or yield stress must be attributed to the depressing influence of increasing stress concentration. With increase in notch depth from zero, the depressing effect of stress concentration, increased at first rapidly to a maximum and then decreases. The depressing effect resulting from the influence of notch angle is most prominent in the curves for work-hardened metals or metal containing a hard microconstituent.

The influence of notches on the breaking stress and ductility of copper and Monel Metal were also determined. Diagrams obtained show the influence of notches on copper in three different degrees of hardness, cold-rolled, half-hard and annealed at 425° C., due to different degrees of prior plastic deformation. Plastic extension is found to cause continuous increase in the technical cohesive strength, and hence tends to cause increase in any specific technical cohesive limit. The continuous decrease in total plastic deformation (ductility) with decrease in the notch angle consequently tends to cause a continuous descent in the curve of breaking stress and this tendency eventually becomes dominant. For annealed copper, the variable plastic deformation has relatively great influence on the curve of breaking stress. At 180° C., this curve is much higher in relation to the curve of ultimate stress than is the curve for cold-rolled copper, the difference being due to the greater work-hardening capacity and greater ductility of the annealed copper. For the same reason, the breaking stress of an unnotched specimen of annealed copper is greater than the disruptive stress. For cold-rolled copper, however, the influence of the radial stress ratio predominates, and the disruptive stress is greater than the breaking stress of an unnotched specimen. The breaking-stress curves obtained with root radius 0·004 in. and 0·001 in., unlike the corresponding curves of ultimate stress, generally are below the corresponding curves obtained with root radius 0·01 in.

The influence of notches on the breaking stress of Monel Metal was determined when the alloy was cold-drawn to 40% reduction in sectional area and when fully annealed at 750° C. The scatter of experimental points is

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considerably greater in the diagrams for Monel Metal than in those for copper, but in general the diagrams for Monel Metal are similar to those for copper and lead to the same conclusions.

The notch effect may be minimised by repeatedly interrupting the tensile tests and machining the specimen to cylindrical form. After each interruption of the local contraction test, specimens of oxygen-free copper and Monel Metal were machined so as to increase the angle of the notch formed by the contraction, but the diameter on each side of the contracted area was not reduced enough to allow local contraction to start in a new place. The effects of this procedure are revealed by the changes in the course of the curves of flow-stress, as, after each machining during the progress of local contraction, the initial flow stress on retest was lower than the flow stress at interruption. When an unnotched specimen of oxygen-free copper is completely fractured by either continuous or interrupted tension, the breaking stress based on measurement of the sectional area after fracture is too high, due to a rim effect resulting from the continued plastic deformation of the rim of the minimum cross-section after fracture has started near the centre.

Evidence obtained from the diagrams indicated that the ductility values plotted are generally too high, and that the nominal values for ductility are higher than the true values. This is caused by two factors—the first, the rim effect; and the second, the deformation gradient. The relation between the fine ductility and the nominal ductility is also shown to depend on the location of the origin of fracture. If fracture of a notched specimen starts near the centre of the cross-section, where the plastic deformation is least, the true ductility is less than the nominal ductility, but if the fracture starts near the circumference where the plastic deformation is greatest, the true ductility is greater than the nominal ductility.

The influence of notches on the breaking stress and ductility of the 13·2 chromium-nickel steel is illustrated by a pair of correlated diagrams of the same two types that have been used for copper and Monel Metal. The breaking stress curves in these two diagrams differ greatly in form from the corresponding curves obtained with copper and Monel Metal. Whereas the curves for the latter alloys have a single rise and descent, the curves for the steel have two reversals. In each of these diagrams, all the curves of breaking stress rise to a maximum, then descend. The curve for shallow notches continues its descent, first at a decreasing rate, then at an increasing rate, while the curves representing deeper notches diverge from the curves representing shallow notches by traversing a minimum, reascending, traversing a second maximum, then probably redescending. The complex form of the curves cannot be attributed to variable stress concentration as the variation of theoretical stress concentration with the notch angle is represented by a continuous rising curve without reversal. On account of the difficulty of fitting together the fractured ends of specimens of this steel, the presence or absence of the rim effect could not be determined.

The influence of notches on the breaking stress and ductility on the 0·2% carbon steel was shown by a pair of correlated diagrams of the same type, when it was found that corresponding diagrams for both the chromium-nickel steel and the carbon steel were similar. Experiments made with the 0·04% carbon steel in the cold-drawn condition and after annealing were confined to deeply notched specimens. The breaking-stress curves, representing notches with root radius 0·002 and 0·004 diverge from the curve representing notches with root radius 0·01 and take a lower course. The lower course of these curves for annealed 0·04% carbon steel, however, is not associated with an elevation of the corresponding curves of ultimate stress. With decrease in the notch angle below 60°, the breaking stress, apparent ultimate stress, and ductility drop rapidly, and there is evidence of premature fracture. With cold-drawn 0·04% carbon steel, initially unnotched specimens show good ductility. The introduction of even a wide-angled notch, however, causes considerable decrease in ductility and an increase in the ultimate stress and breaking stress.

Application of Electron Microscope to Study of Aluminium Alloys

By F. Keller and A. H. Geisler

SOME of the important changes that take place in the structure of aluminium alloys are largely submicroscopic in character. This is especially true of the changes that accompany age-hardening and recrystallisation. Although improved metallographic practices have been helpful in indicating some of these changes indirectly, results are limited by the resolving power of optical microscope lenses. The electron microscope provides a new means for investigating the fine structure of metals.

Several unique methods have been devised to permit the examination of the structure of opaque samples by the electron microscope. These are all based on the principle of producing a very thin film that represents the prepared surface of the opaque metal sample, which can be examined in the transmission microscope. The available methods fall into three categories, depending on the manner in which the film is obtained. With the oxide-film method a very thin surface layer of the metallographic sample is converted into oxide by a thermal, chemical or anodic treatment. After removal from the metal sample by one of several special techniques, this oxide film is examined in the electron microscope, and is found to portray the structure of the original metal surface. Films formed on aluminium, nickel, iron, and a nickel-beryllium alloy by heating; films formed on iron by chemical action; and films formed on aluminium by anodic oxidation, have been examined.

The other two methods consist in making the thin film in the form of a mould or replica of the surface contour of an etched sample. With the negative replica method the thin film is made directly on the sample; with the positive replica method it is made on a negative reproduction of the sample. With both methods, variations in the contour of the metal sample, caused mainly by etching, produce variations in the thickness of the surface replica. Because of the direct dependence of the amount of scattering of the illuminating electrons upon the thickness of the film penetrated, only the variations in thickness of the replica are responsible for tones in the electron image.

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Negative replicas are made by forming a thin film of some suitable material directly on the polished and etched metal sample, and derive their name from the fact that after removal from the sample they have the high and low points in the sample reversed. Negative replicas for the examination of metallographic samples have been made by flowing on to the metal surface solutions of lacquers such as collodion in volatile solvents and by evaporating or electro-depositing metals such as aluminium, beryllium or chromium on to the sample surface. Positive replicas are made by a two-step process in which an initial negative mould is first made from the metal surface and then the thin replica is made from the initial mould. Positive replicas are so named because they have high and low points corresponding directly to those of the metallographic sample.

The choice of the particular process to be used depends to a large extent upon the metal or alloy to be examined and upon the specific features under investigation. This paper presents some of the results that have been obtained with both the oxide-film method and some of the replica methods in the study of aluminium alloys with the electron microscope. These results are encouraging. Many of the structures shown in this paper are far beyond resolution by the optical microscope. Available methods for preparing specimens are compared and the results illustrated. A new method for preparing structureless anodic oxide films for use as electron microscope specimens is described in detail.

Structure of Copper-Zinc Alloys Oxidised at Elevated Temperatures

By F. N. Rhines and B. J. Nelson

A SERIES of 18 copper-zinc alloys containing from 10% to 98% zinc was oxidised at different temperatures to determine the effect of the structure of the oxide deposited in the scale layers at elevated temperatures. Alloys were prepared by melting oxygen-free high-conductivity copper and electrolytic zinc under borax and chill casting as ingots 12 in. × 2 in. × 1 in. The cast surfaces were cleaned and, wherever possible, the bars were reduced 75% by cold-rolling. Specimens ½ in. × ½ in. × ¼ in. were then cut from the rolled plates or cast bars and were polished on 000 emery paper. Two kinds of oxidation treatments were applied: (1) Heating with free access to the air; and (2) heating in a closed iron chamber packed with a mixture of cuprous oxide and copper metal (powder or foil) using in all cases an electrically controlled (+5° C.) muffle furnace. When necessary to preserve the scale intact, the specimens, heated in air, were immersed in Wood's metal before they had cooled much below the heat-treating temperature. Oxidation was carried at temperatures of 400°, 500°, 600°, 700° and 800° C. for periods varying from over 2,000 hours at the lower temperature to 24 hours at the higher temperature.

After oxidation, the specimens were cross-sectioned, polished, etched, and examined by conventional metallographic techniques. Photographs of the structure were obtained and the systematic features of the structures listed, special attention being paid to the presence of cuprous oxide and/or zinc oxide in the scale or sub-scale. From these structures and from previous knowledge of the mechanism of oxidation in simple systems, a general theory of the process of oxidation in copper-zinc alloys is advanced.

Copper oxide appears only in the external scale, and then only when the oxygen pressure in the attacking atmosphere is above the decomposition pressure of cuprous oxide, and at the same time the zinc delivery to the surface is inadequate to permit the formation of a continuous film of zinc oxide. Zinc is delivered to the front of the reaction by diffusion through the metal and this means that its rate of delivery increases with rising temperature and with an increased concentration gradient. The concentration gradient is steepest at the beginning of oxidation and in those alloys richest in zinc. Oxygen is delivered to the front of reaction in one or more of several ways, depending upon the circumstances: (1) By direct contact of the gas at or within a crevice; (2) by the decomposition of cuprous oxide in contact with zinc; or (3) by diffusion through the metal.

Where zinc and oxygen meet in sufficient concentration, zinc oxide forms. This may occur within the metal, whereupon a true subscale forms, at a surface where a true external scale forms, or beyond a surface (an external surface, a crevice, or within a cavity) where the zinc vapour oxidises. A continuous film of zinc oxide provides a barrier to the diffusion of the reactants, so that its growth is therefore slow. The withdrawal of zinc from alloys containing in excess of 10% of zinc results in the formation of cavities, which are larger, more elongated perpendicular to the surface, and more interconnecting, the greater the zinc content of the alloy.

The deposition of zinc oxide within a metal matrix or within holes in the metal causes the latter to expand, and this produces the stress necessary to bring about spalling. Where zinc oxide deposits as a mixture with metal, it tends to become the continuous constituent periodically (Liesegang structure) and spalling cracks follow such zones. The precipitation of zinc oxide within the alpha phase of the alloy occurs generally at high temperatures, and chiefly at grain boundaries at low temperatures. When zinc is being withdrawn from the alloy at a relatively high rate, a complete series of the possible metal phases, as dictated by the phase diagram, is formed in concentric shells, from alpha (at the outside) to the phase present in the core alloy at the centre. If the outward diffusion of zinc is retarded by a protective film of zinc oxide, the composition of the core alloy is maintained to the interface with the oxide.

With certain evident exceptions, these factors are active over the entire range of alloy compositions, but the relative importance of each differs with the composition of the alloy, the temperature of oxidation, and the oxygen concentration of the atmosphere. The details of the process must also change with time during oxidation, for whenever a barrier of zinc oxide is established, the reaction is greatly retarded and then accelerates again, when, through spalling or spheroidisation, the barrier is broken. In pack oxidation the outer layers of the scale grow out of the debris of the inner layers and these in turn must change in the character of the voids developed in them and the degree of subsequent expansion as the zinc concentration gradient becomes less steep. Superimposed upon these complications is the influence of the shape of the specimen upon its response to the contracting and expanding forces that lead to spalling.

From *Metals Technology*, 1943, vol. 10, No. 6; and A.I.M.E. *Tech. Publ.*, No. 1617, 24 pp.

Effect of Minor Alloying Elements on the Corrosion Resistance of Steel and Iron Pipes

By M. K. Sheludko, F. G. Rosenberg and J. A. Satunovski.

AN attempt to find highly corrosion-resistant pipes containing only small additions of expensive metals is reported by the authors. The selected pipes will be used for water supply and drainage of the future Palace of Soviets in Moscow. Some 8,000 samples have been tested. They belonged to six types of alloyed steel and 16 types of alloyed cast iron. The chemical composition of the steels and of three cast-iron types is given in Tables I and II.

The steel samples were used with their "natural" surface as well as with etched and sand-blasted surfaces; and cast-iron samples with their natural surfaces only. All samples were degreased, dried, and weighed before the corrosion experiments started. After the test, the corrosion products were removed from the surface of the samples, the samples weighed again, and the loss of weight calculated. The loss of weight of the commercial steel AS, divided by that of an alloyed steel was termed "the relative corrosion resistance" of this alloyed steel; in the same way, the corrosion resistance of cast-iron samples was compared with that of the commercial cast iron.

TABLE I.

Code Letters.	C.	Mn.	Si.	S.	P.	Mo.	Cr.	Ni.	Cu.	Al.
AS	0·14	0·35	0·05	0·019	0·010	—	0·03	0·03	0·004	—
DS	0·17	0·56	0·30	0·019	0·048	—	0·61	0·25	0·56	—
TK	0·09	0·21	0·33	0·016	0·023	0·19	0·24	0·22	0·41	—
MA	0·19	0·45	0·20	0·016	0·016	—	0·26	0·28	0·61	0·23
MR	0·13	0·41	0·31	0·022	0·113	—	0·61	0·45	0·54	—
KT	0·15	0·49	0·75	0·022	0·130	—	0·82	0·23	0·40	—

TABLE II.

Melt No.	G.C.	C.C.	Si.	Mn.	S	P.	Ni.	Cu.	Ti.	Cr.
52	2·60	0·95	1·75	0·75	0·091	0·150	0·3	0·47	0·14	0·52
12	2·76	0·94	1·49	0·75	0·104	0·101	1·0	0·53	0·05	0·63
Commercial	3·3·4	0·6–0·8	2·2·2	0·6–1·1	0·07–0·08	0·110	—	—	—	—

The corrosion of steel pipes was determined mainly in four sets of tests: (1) The samples were subjected for 1·5–6 months to the daily cycle in a fog box as follows:—3 hours in town gas, 1 hour in a fog of water, 1 hour in humid atmosphere, 1 hour in air, again 3 hours in gas, 1 hour in fog, and 1 hour in humid air, and then 13 hours in air. (2) The samples were dipped ever 30 mins. for 15 mins. in a 3% NaCl solution, the rest of the time was spent in air. The total length of test was 6 months. (3) Same, but tap water substituted for 3% NaCl solution. (4) Short lengths of pipes were used in a hot water circulating system for 12 months.

The results are collected in Table III. The figures in front of the brackets are for pipes 165 mm. in diameter, and those within the brackets for pipes 21 mm. in diameter. The hot-water test was carried out on pipes of 48 mm.

Among the cast-iron samples, the type No. 52 showed the best performance as a 2 in. pipe, and the type No. 12 as a 12 in. pipe. The relative corrosion resistance of No. 52, after a test duration of two months, was, according to (2) above, 1·7–1·8; after a test according to (3) above, 2·0; after a 6 months' test in a fog-box, 1·2; and after 1 year's usage in the drainage system of a building, 2·0. The cycle in the fog-box consisted of: 3 hours in air containing 0·1% of ammonia, 0·1% of hydrogen sulphide, and 0·5% of carbon dioxide, 1 hour in a fog of 0·1% sodium chloride solution, 1 hour in humid air, etc., as above. The relative corrosion resistance of No. 12, after a test in fog-box as just described, was 1·3, after a test as (2), 1·9, and after a test as (3), 2.

TABLE III.

Code Letters.	Relative Corrosion Resistance of Steel Pipes.			
	(1) Fog Box.	(2) 3% NaCl.	(3) Water.	(4) Hot Water.
AS	1·0 (1·0)	1·0 (1·0)	1·0 (1·0)	1·0
DS	1·5 (1·3)	2·4 (3·0)	1·5 (1·2)	1·8
MA	1·5 (1·05)	2·45 (3·2)	1·5 (1·0)	1·7
TK	1·4 (1·05)	2·7 (3·6)	1·5 (1·2)	0·9
KT	1·75 (1·05)	2·5 (3·3)	1·5 (1·5)	2·1
MR	1·5 (1·25)	2·45 (3·8)	1·5 (1·5)	1·8

From the Second (Russian) Conference on Corrosion of Metals (Proceedings, 1943, vol. ii, p. 104).

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